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# FERTILIZER RESOURCES AND REQUIREMENTS OF THE UNITED STATES

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# FERTILIZER RESOURCES AND REQUIREMENTS OF THE UNITED STATES

Since the early days of our country, fertilizer has played a part in the production of food in broader areas, under wider ranges of farming conditions, and in greater quantities from year to year. In order to meet the needs of a continually growing population, sustained high-level production and the improvement of our soil resources are essential. The Nation can be strong only so long as those objectives can be attained.

There is relatively little additional land to be brought into production, so that for practical purposes our increasing needs for food and fiber must come in large part from the land now being used. More than 70 million acres of land formerly used for the support of workstock are now producing food and fiber. The transition from workstock to machinery is almost complete and no further substantial contribution to our need can come from this source. The population of the United States has grown from 132 million to 152 million since 1940, an increase of 15 percent. Each year there are 2 to 2-1/2 million more people to feed, and it is probable that by 1975 our population will reach 190 million or more persons. Fertilizer offers one of the most effective ways of increasing and maintaining the productivity of our soils, whether it is used on pasture, hay, grains, or row crops. The importance of fertilizer to the Nation's welfare can hardly be over emphasized.

Fertilizer can also make a major contribution to balanced farming, which is a major step in attaining sustained high-level production. Fertilizer is now being used over much wider areas than in the past, and substantial expansion of supplies will be required to meet the needs of these areas, particularly in the Middle West. Not only does fertilizer make a major contribution toward production but its use is generally profitable to the farmer. Increased technical knowledge of how to combine factors of production to attain higher yields has enhanced the returns that may be expected from the use of fertilizer. Also, fertilizer contributes to economical production because through its use a given quantity of product can be obtained with substantial savings in manpower, fuel, equipment, etc.

The consumption of plant nutrients as commercial fertilizer reached a new record in the year ended June 30, 1951, the 12th consecutive year of increase. The consumption of nitrogen (N) and potash ($K_2O$) each has doubled in the last 7 years, while the consumption of phosphoric oxide ($P_2O_5$) has doubled in the last 10 years. Even so, the supplies were short of the demands in most of the years.

The increasing importance of fertilizer to our agricultural production and the prospects for further large expansion in its use, emphasize the need for reviewing the situation with respect to this essential commodity, particularly as regards our resources of the basic materials and the status of processing methods and facilities to meet the Nation's future requirements of plant nutrients.

## I. HISTORY AND PATTERN OF FERTILIZER PRODUCTION AND USE

The placing of fish in hills of corn to fertilize the crop was being practiced by certain Indian tribes along the Atlantic Coast at the time of the arrival of the earliest colonial settlers. This practice and other measures for increasing the yields of crops were adopted and developed by the colonists, who were entirely dependent on local sources of such materials as animal and plant residues, lime, and marl for their supplies of plant nutrients.

During the period 1800 to 1850 fundamental advances were made in the science of plant nutrition, and the foundation was laid for the commercial fertilizer industry--developments that resulted largely from the studies and teachings of Liebig in Germany and from the work of Lawes in England. It was in this period that Peruvian guano, Chilean sodium nitrate, and superphosphate, as well as certain other materials, were first used as fertilizers in Europe and the United States.

The last half of the nineteenth century witnessed the commercial development of the German potash deposits; the discovery and utilization of the phosphate-rock deposits of South Carolina, Florida, and Tennessee; and the initiation of the domestic superphosphate, byproduct ammonia, and mixed-fertilizer industries. During this period the production of commercial fertilizer in the United States increased from about 32,000 short tons in 1859 to nearly 3 million tons in 1899. In its early years the industry was largely centered in Baltimore and Charleston.

Subsequent developments have not only freed the United States from dependence on foreign sources for supplies of nitrogen and potash and have greatly enhanced our security in phosphate resources but they have assured our continued independence in these respects for many years to come. Among the world countries the United States now holds the premier position in production of nitrogen and phosphate fertilizers. Our production of potash is exceeded only by that of Germany.

In general, the soils of the eastern seaboard are inherently low in native fertility. For this reason and because they had been subjected to fertility-depleting methods of farming for a much

longer period of time than the soils in other parts of the country, it was only natural that the domestic manufacture and use of commercial fertilizer as an aid to crop production should have had its beginning in the Atlantic Coast States. Ready accessibility to supplies of the essential raw materials was also an important factor. Although the greater portion of the Nation's consumption of fertilizer is still used in this region, fertilizer is now a highly important factor in crop production in most parts of the country.

Changes in farming and soil-management practices and in production programs have been accompanied by changes in the crop-pattern of fertilizer consumption. Formerly, the emphasis was on the fertilization of cash crops, while today major effort is being directed toward increasing the use of fertilizer on grass and other forage crops. Furthermore, modern methods of soil testing have contributed greatly to the more rational and efficient use of fertilizers, by enabling rapid determination of the status of the soil with respect to certain plant-nutrient elements and factors.

At the turn of the century, little or nothing was known of the plant requirements for the so-called trace elements, such as boron, copper, manganese, and zinc. In fact, the essentiality of these elements for plant nutrition and growth had not even been recognized. The symptoms of trace-element deficiencies are now known for most crops, and the areas of soil occurrences of such deficiencies have been delineated in many parts of the country, with the result that increasing quantities of trace-element compounds are being used—both for direct application to the soil and for inclusion in mixed fertilizers.

Under the impetus of Government agricultural conservation programs, great progress has been made in the use of soil-liming materials.

Developments in methods and equipment for applying fertilizers to the soil have resulted in more economical and efficient use of plant nutrients.

## FERTILIZER PRODUCTION

The commercial fertilizer industry in the United States dates from about 1850 when it was initiated in Baltimore. In its beginning the industry was based chiefly on materials of organic origin, largely wastes and byproducts of other industries. The manufacture and processing of fertilizers has since developed into a major segment of the American chemical industry which in 1950 supplied to the Nation's farmers some 19.8 million tons of products valued at over 750 million dollars. These products contained more than 4.4 million tons of the primary plant nutrients (nitrogen, $P_2O_5$, and $K_2O$) and an even larger total quantity of the plant-nutrient forms of calcium, magnesium, and sulfur.

The operations of the industry as it is constituted today include the mining and processing of phosphate rock and potash minerals, the fixation of atmospheric nitrogen, and the manufacture of mixed fertilizers. These operations involve the handling of huge quantities of solid, liquid, and gaseous materials. They require the use of complicated machinery and equipment and expert knowledge of intricate chemical processes.

Although the industry has made remarkable progress in the last 50 years, there is still room for great improvement, and further developments of far-reaching importance can be expected. The industry will be faced in the future, as in the past, with the problem of supplying ever increasing quantities of better fertilizers to meet the continually expanding requirements of American agriculture. This problem is the responsibility not only of the fertilizer industry itself but of all agencies and organizations, both governmental and private, concerned with the Nation's agricultural production.

During the period 1900 to 1950 the manufacturing processes and the characteristics and types of fertilizer materials and mixtures underwent important changes. Natural organic materials, formerly the chief source of nitrogen for commercial fertilizers, were superseded largely by chemical products. Liquid and gaseous fertilizers came into use. The concentrations of the primary plant nutrients (N, $P_2O_5$, and $K_2O$) in fertilizer materials and mixtures were increased in proportions ranging to more than 100 percent. Marked improvement was made in the physical condition of the materials and mixtures and in their packaging.

Farmer cooperatives have become an increasingly important factor in the domestic fertilizer industry. In 1947-48, 52 cooperative associations operated 86 plants and produced more than 8 percent of the fertilizer (17,818,401 short tons) used in the United States and Territories. By April 1951 the number of associations had increased to 61 and the number of plants to 101.

## NITROGEN

Aside from a very small quantity of byproduct ammonium sulfate, the Nation's production of commercial-fertilizer nitrogen in 1900 was derived entirely from natural organic materials, chiefly oilseed meals, fish products, animal tankages, and dried blood. Such materials supplied nearly 90 percent of the domestic consumption of fertilizer nitrogen in that year. Owing, however, to their limited supply, low analysis, high unit cost, and the greater value of a number of the materials as protein feeds for livestock, less than 4 percent of our consumption of commercial-fertilizer nitrogen is now in the form of natural organics.

Table 1. - Production of Synthetic Ammonia in the United States, 1939 and 1941-1950

| Calendar year | Production 1/ |
|---|---|
| | Short tons |
| 1939 | 310,822 |
| 1941 | 501,271 |
| 1942 | 543,352 |
| 1943 | 543,380 |
| 1944 | 543,651 |
| 1945 | 548,655 |
| 1946 | 725,537 |
| 1947 | 1,114,000 |
| 1948 | 1,089,786 |
| 1949 | 1,294,057 |
| 1950 | 1,565,569 |

1/ Basis 100 percent $NH_3$; excludes military production in war years.

U. S. Bureau of the Census.

Table 2. - Production of superphosphates in the continental United States, 1930-1950

| Calendar year | Available $P_2O_5$ | | |
|---|---|---|---|
| | Normal superphosphate 1/ | Triple superphosphate | Total |
| | Short tons | Short tons | Short tons |
| 1930 | 751,200 | 43,300 | 794,500 |
| 1931 | 455,100 | 22,700 | 477,800 |
| 1932 | 295,400 | 11,400 | 306,800 |
| 1933 | 449,900 | 13,300 | 463,200 |
| 1934 | 477,500 | 31,300 | 508,800 |
| 1935 | 490,200 | 41,000 | 531,200 |
| 1936 | 568,800 | 58,400 | 627,200 |
| 1937 | 728,400 | 76,400 | 804,800 |
| 1938 | 597,200 | 86,000 | 683,200 |
| 1939 | 632,600 | 125,500 | 758,100 |
| 1940 | 724,400 | 151,400 | 875,800 |
| 1941 | 808,900 | 146,300 | 955,200 |
| 1942 | 926,000 | 144,600 | 1,070,600 |
| 1943 | 1,140,879 | 132,292 | 1,273,171 |
| 1944 | 1,213,059 | 126,484 | 1,339,543 |
| 1945 | 1,334,001 | 112,932 | 1,446,933 |
| 1946 | 1,421,197 | 145,044 | 1,566,241 |
| 1947 | 1,683,923 | 172,725 | 1,856,648 |
| 1948 | 1,688,615 | 210,920 | 1,899,535 |
| 1949 | 1,644,584 | 246,827 | 1,891,411 |
| 1950 | 1,684,430 | 309,085 | 1,993,515 |

1/ Includes small quantities of wet-mixed base made by treating mixtures of phosphate rock and nitrogenous organic materials with sulfuric acid.

U. S. Department of Agriculture and U. S. Bureau of the Census.

Although its relative position has been declining in recent years, natural sodium nitrate from Chile has long been an important factor in the domestic fertilizer picture; it supplied about 100,000 tons of nitrogen in 1950. Until 1946, this material and domestic byproduct ammonium sulfate furnished the greater portion of the Nation's consumption of chemical nitrogen as fertilizer.

Fertilizers manufactured from atmospheric nitrogen have played an increasingly important role in the domestic industry since production of calcium cyanamide was started in Canada in 1909. Manufacture of such fertilizers in the United States was placed on a permanent basis with the initiation of commercial production of synthetic ammonia in 1921. Subsequently, synthetic ammonia and its products have supplied a progressively larger portion of the country's consumption of fertilizer nitrogen; the proportion was more than 65 percent in 1950.

A record production of 1,565,569 tons of synthetic ammonia was achieved in 1950 (table 1). This was more than double the output in 1946 and five times that in 1939. It is estimated that 30 percent of the production in 1950 was used for nonagricultural purposes, of which some of the more important were industrial explosives, organic and inorganic chemicals, plastics and kindred products, metal treating, textiles, refrigeration, pulp and paper, petroleum refining, rubber accelerators, and water treating.

The fertilizer products of the domestic synthetic ammonia industry comprise chiefly anhydrous and aqua ammonia, aqueous solutions of ammonia and ammonium nitrate or urea, ammonium nitrate, ammonium nitrate - dolomite mixtures, ammonium sulfate, ammonium phosphates, sodium nitrate, and urea.

Production of solid, nearly pure ammonium nitrate in forms suitable for fertilizer use was an outstanding development during World War II. This was accomplished by converting the nitrate into granules, treating with conditioning agents, and packaging in moisture-proof bags.

## PHOSPHATE

Since the beginning of the domestic fertilizer industry the production of available $P_2O_5$ has been predominantly in the form of normal superphosphate made by mixing ground phosphate rock with sulfuric acid. The product formerly contained 14 to 16 percent of available $P_2O_5$. Owing to the use of higher grades of phosphate rock and to improvements in the process and product, the available $P_2O_5$ content is now 18 to 20 percent. A portion of the present production is marketed in a granular form.

The production of triple superphosphate ranks second to but is considerably lower than that of normal superphosphate. Triple superphosphate usually contains 43 to 48 percent of available $P_2O_5$. It is made by treating phosphate rock with phosphoric acid. Much of the present output is in a granular form. Beginning in 1907, triple superphosphate has been manufactured continuously in the United States with phosphoric acid made by the sulfuric acid process. Since 1930, some triple superphosphate has also been produced continuously with furnace-process phosphoric acid, mostly with electric-furnace acid by the Tennessee Valley Authority.

In 1950 the production of normal and triple superphosphates, which together supply about 90 percent of the $P_2O_5$ used annually as commercial fertilizer in the United States, totaled 1,993,515 tons of available $P_2O_5$ (table 2). This production, an all-time record, was 2-1/4 times that in 1940. A new record for triple superphosphate was also established in 1950, with an output of 309,085 tons of available $P_2O_5$, or double the 1940 production.

The other phosphate fertilizer materials produced in the United States comprise chiefly relatively small tonnages of bonemeal and other natural organic substances, basic slag, ammonium phosphates, and in recent years calcium metaphosphate, liquid phosphoric acid, defluorinated phosphate rock, phosphate rock - magnesium silicate glass, and certain byproduct and spent materials of inorganic origin.

## POTASH

Until World War I, materials of vegetable origin were the principal or only domestic sources of commercial-fertilizer potash, and the potash requirements of American agriculture were met almost entirely by imports from Germany. The placing of an embargo by Germany on the export of potassium salts early in 1915 caused major effort to be directed toward the development of domestic supplies. Although numerous plants were built for recovering potash from brines and other materials, the annual rate of total production at the close of the war was only about 55,000 tons of potash ($K_2O$), less than 25 percent of the country's consumption in 1914.

With the resumption of imports from Germany and the marked decrease in potash prices, most of the domestic producers were forced out of business, with the result that the output dropped to less than 12,000 tons of potash in 1922. Production of potash from the natural brines of Searles Lake, California, was continued, however, and for several years this operation supplied most of the Nation's output.

Initiation in 1931 of production of potash from the subsurface deposits of soluble minerals in New Mexico marked the beginning of developments which by 1941 had made the United States independent of foreign sources of this highly important plant nutrient. Subsequently, the total production progressively increased to an all-time record of 1,286,762 short tons of $K_2O$ in 1950, or 3.4 times the output in 1940.

More than 80 percent of the production is now in the form of nearly pure potassium chloride containing 60 percent or more of $K_2O$. The remainder comprises chiefly lower grades of the chloride (48 to 50 percent of $K_2O$, minimum), potassium sulfate (50 to 52 percent of $K_2O$), sulfate of potash-magnesia (21 to 22 percent of $K_2O$), and manure salts (24 to 26 percent of $K_2O$).

## FERTILIZER CONSUMPTION

The United States consumption of fertilizer and of the three primary plant nutrients (N, $P_2O_5$, and $K_2O$) contained therein increased fairly steadily from 1900 to 1930 (table 3, figure 1). The consumption declined during the depression years and it was not until 1937 that the quantities again reached the 1930 level. From 1937 to 1942 the consumptions of fertilizer and of total plant nutrients each increased about 22 percent. In 1950 the Nation used 19.8 million tons of fertilizer containing more than 4.4 million tons of N, $P_2O_5$, and $K_2O$. These quantities were 91 percent and 111 percent higher than the respective consumptions in 1942. The tonnages of fertilizer and of plant nutrients used in 1950 were respectively 7.2 and 11.2 times those used in 1900.

The greatly accelerated increase in consumption of fertilizer and plant nutrients during the period 1942 to 1950 was influenced, among other factors, by (1) the urgent need for additional food and fiber to meet the domestic and export needs, (2) the greatly improved economic position of the American farmer, (3) the continued decline in the native fertility of large areas of the Nation's soils, and (4) a more general recognition of the potentialities of fertilizer in lowering production costs and increasing crop yields. During most if not all years of this period and through 1951 the supply of plant nutrients was generally insufficient to meet the farmers' demand. It is not possible, however, to make trustworthy estimates of the extent of the deficiencies.

Failure to meet the unprecedented domestic demand for plant nutrients during the last 10 years involved a number of factors. These comprised chiefly (1) insufficient manufacturing and processing facilities and the difficulty of adequately expanding certain

of these facilities, especially during the war and immediate post-war years, (2) the necessity for shipping large quantities of plant nutrients to our allies and the occupied countries, and (3) shortages of some chemicals required for fertilizer manufacture.

There has been considerable change in the average concentrations and ratios of the primary plant nutrients in the total fertilizer consumed in the United States and Territories (table 3). Thus, the plant-nutrient content averaged 22.3 percent in 1950 as compared with 14.4 percent in 1900, an increase of nearly 55 percent. This change resulted from decreased use of low-analysis products, such as kainite and natural organics, and increased use of various high-analysis nitrogen, phosphate, and potash materials.

In 1900 the average $N$-$P_2O_5$-$K_2O$ ratio in fertilizers was 1-4.0-1.4. Subsequently, the ratio has narrowed considerably, especially with respect to $P_2O_5$. In 1950, it was 1-1.8-1.1. During this period the annual consumptions of N and $K_2O$ increased some seventeenfold and thirteenfold, respectively, but the increase in $P_2O_5$ was less than eightfold.

The greater portion of the total annual consumption of commercial fertilizer in the United States is in the form of mixtures--67 to 70 percent in 1942-43 to 1949-50 (table 4). As regards the primary plant nutrients, more than 90 percent of the $K_2O$, about 70 percent of the $P_2O_5$, and 50 to 60 percent of the N is used as mixed fertilizer. The proportions have fluctuated from year to year, usually within rather narrow limits. Since 1946-47 the trends have been downward for $K_2O$ and especially for N. Largely because of the growing recognition of the importance of supplemental applications of nitrogen in the production of many crops, particularly corn and grass, it is expected that the proportion of nitrogen used as materials applied directly to crops will increase substantially.

Farmers are often unable to obtain the desired quantities of straight nitrogen, phosphate, or potash materials, whereas adequate supplies of mixed fertilizers have generally been much more readily available. Correction of this situation is a problem which needs attention.

The average concentration of primary plant nutrients in mixed fertilizers rose from 18.3 percent in 1933-34 to 23.2 percent in 1949-50, an increase of 27 percent. This is an important improvement but the increase in the average nutrient content of the mixtures has not kept pace with that of the fertilizer materials used therein. Although the national average is substantially exceeded in certain parts of the country, notably the New England and Mountain States with respective averages of 28 percent and 30 percent in the year ended June 30, 1950, the opposite is true of the very large fertilizer-consuming area comprising the South Atlantic and South Central

Table 3. - Commercial fertilizers and primary plant nutrients consumed in the United States and Territories, 1900-1950

| Calendar year | Fertilizers[1] | Plant-nutrient content | | | | | Plant-nutrient ratio | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Nitrogen (N) | Available phosphoric oxide ($P_2O_5$) | Potash ($K_2O$) | Total | | | | |
| | | | | | Quantity | Proportion | N | $P_2O_5$ | $K_2O$ |
| | 1,000 short tons | 1,000 short tons | 1,000 short tons | 1,000 short tons | 1,000 short tons | percent | | | |
| 1900 | 2,730 | 62 | 246 | 86 | 394 | 14.4 | 1 | 4.0 | 1.4 |
| 1902 | 3,084 | 70 | 284 | 96 | 450 | 14.6 | 1 | 4.1 | 1.4 |
| 1904 | 3,704 | 84 | 344 | 122 | 550 | 14.8 | 1 | 4.1 | 1.5 |
| 1906 | 4,249 | 99 | 391 | 144 | 634 | 14.9 | 1 | 3.9 | 1.5 |
| 1908 | 4,449 | 107 | 400 | 160 | 667 | 15.0 | 1 | 3.7 | 1.5 |
| 1910 | 5,547 | 146 | 499 | 211 | 856 | 15.4 | 1 | 3.4 | 1.4 |
| 1912 | 5,852 | 157 | 521 | 222 | 900 | 15.4 | 1 | 3.3 | 1.4 |
| 1914 | 7,194 | 216 | 662 | 237 | 1,115 | 15.5 | 1 | 3.1 | 1.1 |
| 1916 | 5,214 | 208 | 505 | 16 | 729 | 14.0 | 1 | 2.4 | 0.1 |
| 1918 | 6,580 | 217 | 625 | 46 | 888 | 13.5 | 1 | 2.9 | 0.2 |
| 1920 | 7,296 | 228 | 660 | 258 | 1,146 | 15.7 | 1 | 2.9 | 1.1 |
| 1922 | 5,798 | 191 | 516 | 226 | 933 | 16.1 | 1 | 2.7 | 1.2 |
| 1924 | 6,999 | 252 | 630 | 259 | 1,141 | 16.3 | 1 | 2.5 | 1.0 |
| 1926 | 7,531 | 286 | 701 | 290 | 1,277 | 17.0 | 1 | 2.5 | 1.0 |
| 1928 | 8,215 | 342 | 776 | 333 | 1,451 | 17.7 | 1 | 2.3 | 1.0 |
| 1930 | 8,425 | 377 | 793 | 354 | 1,524 | 18.1 | 1 | 2.1 | 0.9 |
| 1931 | 6,541 | 301 | 611 | 275 | 1,187 | 18.1 | 1 | 2.0 | 0.9 |
| 1932 | 4,545 | 214 | 413 | 192 | 819 | 18.0 | 1 | 1.9 | 0.9 |
| 1933 | 5,110 | 240 | 464 | 222 | 926 | 18.1 | 1 | 1.9 | 0.9 |
| 1934 | 5,794 | 275 | 530 | 263 | 1,068 | 18.4 | 1 | 1.9 | 1.0 |
| 1935 | 6,534 | 312 | 597 | 307 | 1,216 | 18.6 | 1 | 1.9 | 1.0 |
| 1936 | 7,222 | 350 | 673 | 350 | 1,373 | 19.0 | 1 | 1.9 | 1.0 |
| 1937 | 8,433 | 412 | 794 | 416 | 1,622 | 19.2 | 1 | 1.9 | 1.0 |
| 1938 | 7,758 | 384 | 744 | 393 | 1,521 | 19.6 | 1 | 1.9 | 1.0 |
| 1939 | 7,993 | 398 | 789 | 409 | 1,596 | 20.0 | 1 | 2.0 | 1.0 |
| 1940 | 8,656 | 419 | 912 | 435 | 1,766 | 20.4 | 1 | 2.2 | 1.0 |
| 1941 | 9,607 | 458 | 994 | 467 | 1,919 | 20.0 | 1 | 2.2 | 1.0 |
| 1942 | 10,331 | 409 | 1,131 | 547 | 2,087 | 20.2 | 1 | 2.8 | 1.3 |
| 1943 | 11,734 | 509 | 1,237 | 643 | 2,389 | 20.4 | 1 | 2.4 | 1.3 |
| 1944 | 13,330 | 635 | 1,405 | 649 | 2,689 | 20.2 | 1 | 2.2 | 1.0 |
| 1945 | 13,988 | 641 | 1,435 | 752 | 2,828 | 20.2 | 1 | 2.2 | 1.2 |
| 1946 | 16,087 | 759 | 1,671 | 854 | 3,284 | 20.4 | 1 | 2.2 | 1.1 |
| 1947 | 17,398 | 836 | 1,775 | 879 | 3,490 | 20.1 | 1 | 2.1 | 1.1 |
| 1948 | 17,596 | 841 | 1,843 | 956 | 3,640 | 20.7 | 1 | 2.2 | 1.1 |
| 1949 | 17,927 | 912 | 1,884 | 1,064 | 3,860 | 21.5 | 1 | 2.1 | 1.2 |
| 1950[2] | 19,758 | 1,126 | 2,071 | 1,215 | 4,412 | 22.3 | 1 | 1.8 | 1.1 |

1/ Includes fertilizers distributed by Government agencies; phosphate rock, gypsum, and sulfur for direct application to the soil; trace-element fertilizers such as borax and copper, manganese, and zinc compounds; and other plant-nutrient materials. Does not include liming material.
2/ Preliminary.

U. S. Department of Agriculture

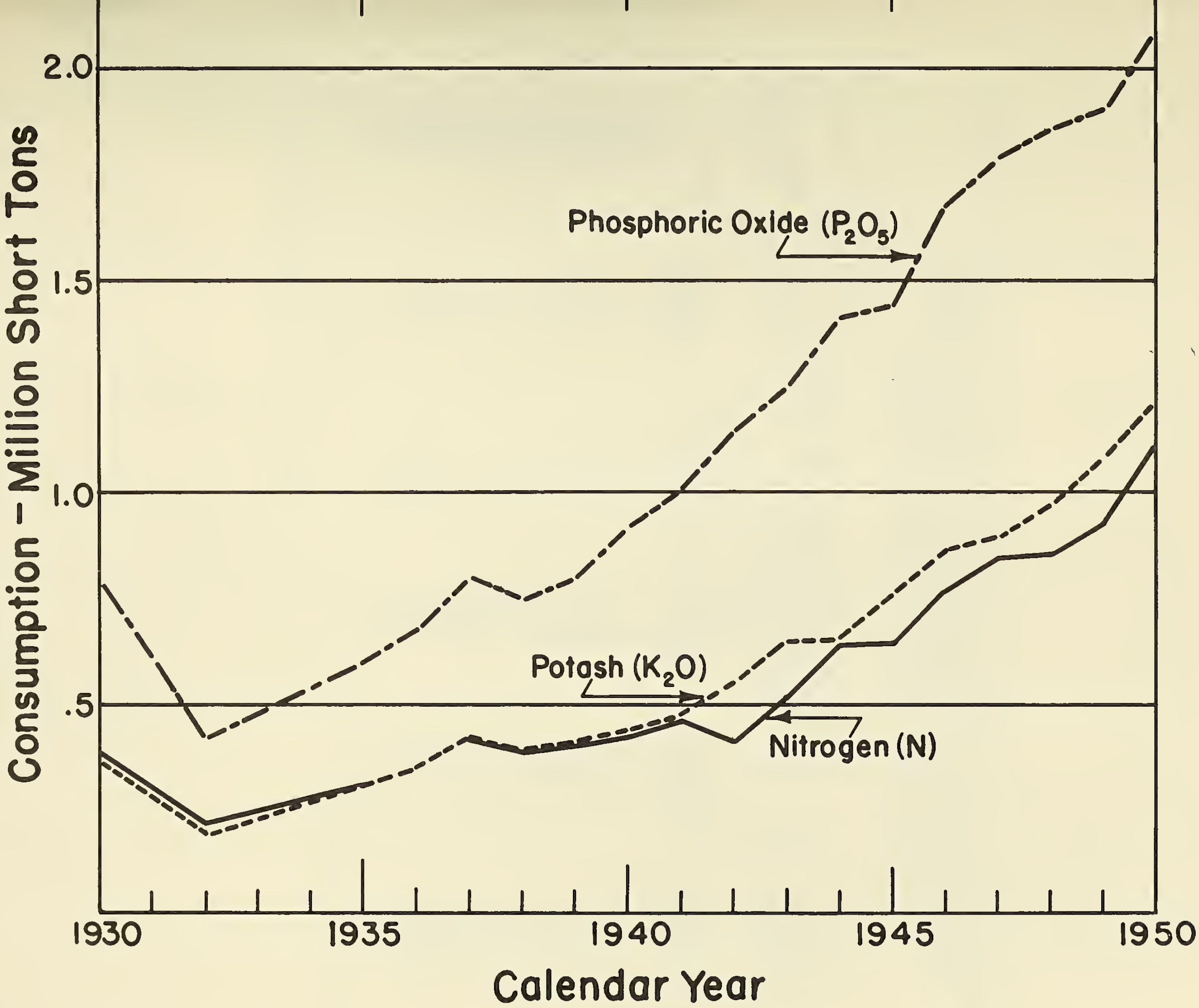


Figure 1. - Consumption of primary plant nutrients as commercial fertilizer in the United States and Territories, 1930 - 1950.

Table 4. - Statistics of mixed fertilizers and their content of primary plant nutrients in the United States and Territories, years ended June 30, 1934, 1939, 1943-1950

| Year ended June 30 | Portion of total consumption | | | | Average content of $N + P_2O_5 + K_2O$ |
|---|---|---|---|---|---|
| | Fertilizer | Plant nutrient | | | |
| | | Nitrogen | Available $P_2O_5$ | $K_2O$ | |
| | Percent | Percent | Percent | Percent | Percent |
| 1934 | 74.2 | 56.3 | 74.6 | 84.9 | 18.3 |
| 1939 | 71.1 | 52.8 | 64.7 | 84.2 | 19.3 |
| 1943 | 67.2 | 53.8 | 65.8 | 93.1 | 21.6 |
| 1944 | 69.9 | 54.3 | 69.9 | 93.9 | 20.9 |
| 1945 | 67.3 | 56.3 | 68.9 | 92.6 | 21.6 |
| 1946 | 67.9 | 57.2 | 68.0 | 93.2 | 21.6 |
| 1947 | 69.7 | 59.7 | 70.9 | 95.4 | 21.4 |
| 1948 | 68.5 | 57.6 | 70.6 | 94.8 | 21.9 |
| 1949 | 69.2 | 55.7 | 71.3 | 93.1 | 22.6 |
| 1950 | 67.0 | 49.3 | 68.9 | 92.2 | 23.2 |

U. S. Department of Agriculture.

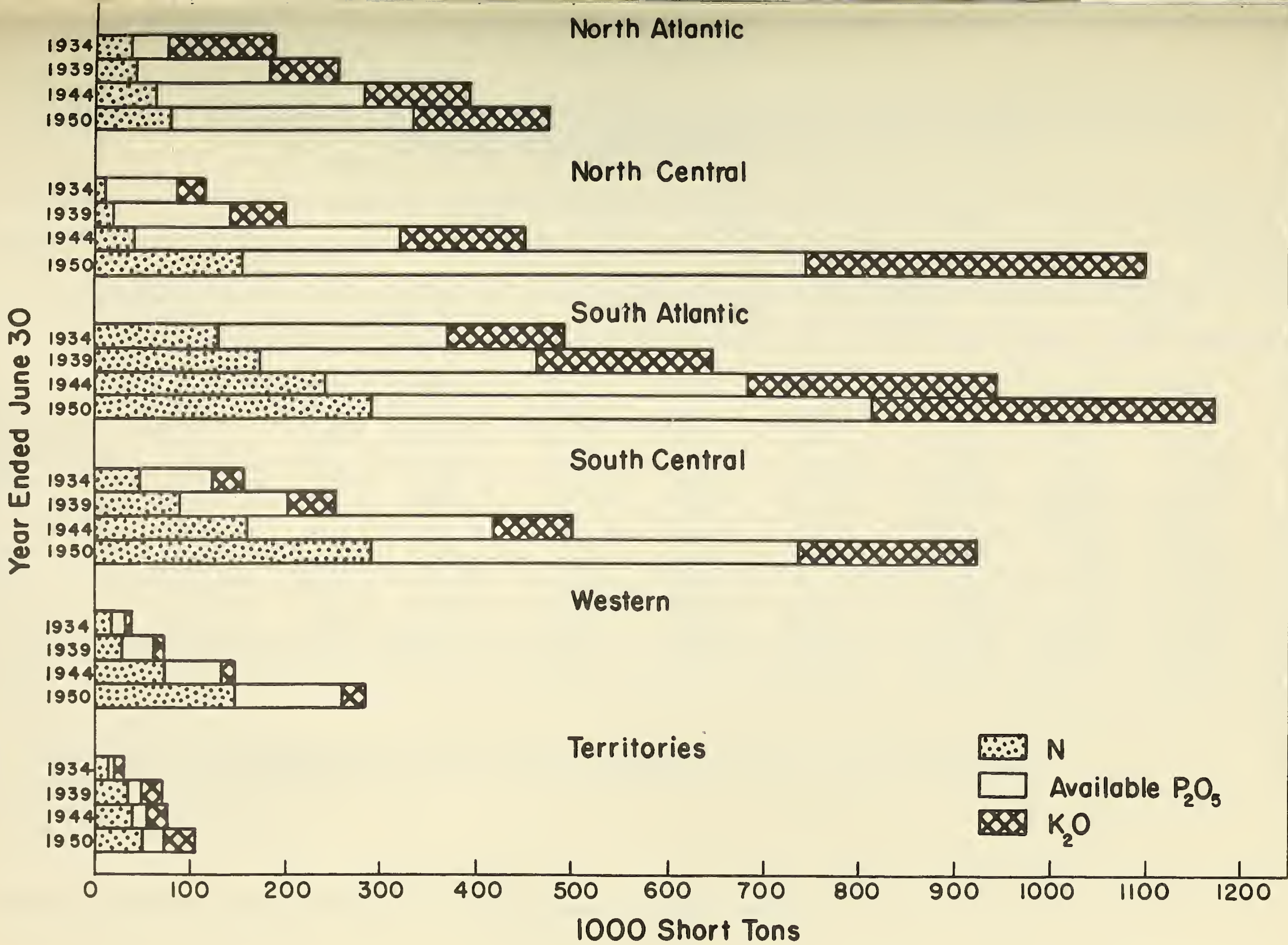


Figure 2. - Regional consumption of primary plant nutrients as commercial fertilizer in the United States and Territories, years ended June 30, 1934, 1939, 1944, and 1950.

Table 5. - Distribution of commercial-fertilizer consumption in the continental United States by principal crops, 1929, 1938, 1942, 1946, 1949-50

| Crop | 1929 | | 1938 | | 1942 | | 1946 | | 1/ 1950 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity | Portion of total | Quantity | Portion of total | Quantity | Portion of total | Quantity 2/ | Portion of total | Quantity 2/ | Portion of total |
| | 1,000 short tons | Percent | 1,000 short tons | Percent | 1,000 short tons | Percent | 1,000 short tons | Percent | 1,000 short tons | Percent |
| Corn | 1,650 | 20.7 | 1,636 | 21.6 | 2,204 | 22.0 | 2,823 | 19.2 | 4,461 | 24.8 |
| Cotton | 2,230 | 28.0 | 1,462 | 19.3 | 1,461 | 14.6 | 1,559 | 10.6 | 1,619 | 9.0 |
| Small grains | 1,105 | 13.8 | 1,087 | 14.3 | 1,407 | 14.1 | 2,573 | 17.5 | 3,310 | 18.4 |
| Tobacco | 546 | 6.8 | 505 | 6.7 | 536 | 5.3 | 779 | 5.3 | 738 | 4.1 |
| Potatoes | 675 | 8.5 | 560 | 7.4 | 709 | 7.1 | 1,221 | 8.3 | 756 | 4.2 |
| Sweet potatoes | 115 | 1.4 | 133 | 1.8 | 149 | 1.5 | (3)/ | (3)/ | (3)/ | (3)/ |
| Hay | 165 | 2.1 | 312 | 4.1 | 705 | 7.1 | 824 | 5.6 | 935 | 5.2 |
| Pasture | (4)/ | (4)/ | 161 | 2.1 | 584 | 5.8 | 1,088 | 7.4 | 1,295 | 7.2 |
| Vegetables | 420 | 5.3 | 323 | 4.3 | 894 | 8.9 | 5/ 1,323 | 5/ 9.0 | 5/ 1,367 | 5/ 7.6 |
| Fruits | 340 | 4.3 | 339 | 4.5 | 667 | 6.7 | 926 | 6.3 | 756 | 4.2 |
| Other crops | 729 | 9.1 | 1,053 | 13.9 | 692 | 6.9 | 1,588 | 10.8 | 2,752 | 15.3 |
| Total | 7,975 | 100.0 | 7,571 | 100.0 | 10,008 | 100.0 | 14,704 | 100.0 | 17,989 | 100.0 |

1/ Year ended June 30.
2/ Estimated from the original data which were expressed in terms of plant nutrients.
3/ Included with vegetables.
4/ No data; very low.
5/ Includes sweet potatoes.

National Fertilizer Association and U. S. Department of Agriculture.

Table 6. - Consumption of agricultural liming materials on farms of the continental United States, 1930-1950

| Calendar year | Consumption | Calendar year | Consumption |
|---|---|---|---|
| | 1,000 short tons | | 1,000 short tons |
| 1930 | 3,498 | 1940 | 13,434 |
| 1931 | 2,549 | 1941 | 15,952 |
| 1932 | 1,840 | 1942 | 17,886 |
| 1933 | 1,627 | 1943 | 17,788 |
| 1934 | 2,434 | 1944 | 24,515 |
| 1935 | 3,292 | 1945 | 22,357 |
| 1936 | 6,305 | 1946 | 29,462 |
| 1937 | 6,801 | 1947 | 30,283 |
| 1938 | 7,048 | 1948 | 25,686 |
| 1939 | 8,003 | 1949 | 27,902 |
| | | 1950 | 29,842 |

National Lime Association, Agricultural Limestone Institute, and National Agricultural Limestone Association (1948-1950).

States—20 percent and 21 percent, respectively. For the most of the Nation the average plant-nutrient content of mixed fertilizers can be raised considerably, with much economy to the farmer.

## REGIONAL CONSUMPTION

As one would expect, the consumption of fertilizer varies considerably among the different regions of the country. Perhaps the most important factors influencing the consumption are (1) the fertility status of the soil and (2) the farming system.

For many years the South Atlantic and Gulf States, which are generally low in native soil fertility, have used a very large portion of the Nation's annual consumption of fertilizer. The consumption has progressively increased, however, in other regions, notably the North Central States, where the fertility status of the soil was originally at a much higher level than in the South Atlantic and Gulf States.

In a grain, legume hay, and livestock system of farming, crop residues and farm manure, if properly utilized, substantially reduce commercial-fertilizer requirements. Thus, in a number of States, notably in the North Central and Mountain regions, farm manure supplies to the soil much larger quantities of plant nutrients than does commercial fertilizer. On the other hand, farm manures furnish only a small portion of the plant nutrients applied to the soils of the South Atlantic and Gulf States.

The consumptions of the three primary plant nutrients at intervals during the period 1933-34 to 1949-50 are shown by regions 1/ in figure 2.

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1/ The units comprising the regions are as follows: North Atlantic--Maine, N. H., Vt., Mass., R. I., Conn., N. Y., N. J., Pa.; North Central--Ohio, Ind., Ill., Mich., Wis., Minn., Iowa, Mo., N. Dak., S. Dak., Nebr., Kans.; South Atlantic--Del., Md., D. C., Va., W. Va., N. C., S. C., Ga., Fla.; South Central--Ky., Tenn., Ala., Miss., Ark., La., Okla., Tex.; Western--Mont., Idaho, Wyo., Colo., N. Mex., Ariz., Utah, Nev., Wash., Oreg., Calif.; Territories--T. H., P. R. The data for 1933-34 do not include Hawaii.

In 1933-34 the South Atlantic region used 50 percent of the national consumption of commercial plant-nutrient nitrogen, while the North Central region used only 4 percent. In 1949-50, however, the respective figures were 29 percent and 15 percent. The growing need for nitrogen in the North Central region is indicated by the fact that the consumption of this nutrient in 1949-50 was 14 times the consumption in 1933-34.

The South Atlantic region has yielded to the North Central region as the largest phosphate-consuming area. The latter region used nearly 8 times as much $P_2O_5$ in 1949-50 as in 1933-34. The proportionate increase in the Western region was even larger.

The South Atlantic region has also yielded to the North Central region as the leader in potash consumption. The consumption in the latter region in 1949-50 was about 12.5 times that in 1933-34.

## CONSUMPTION BY CROPS

For many years fertilizers were chiefly used on such cash crops as cotton, tobacco, potatoes, and vegetables, and the heaviest rates of application were generally made to these crops. The need for a better balance in the production of food, feed, and fiber has been a major factor in altering the distribution of fertilizer consumption by crops. The grass-land program jointly sponsored by the U. S. Department of Agriculture and the Land Grant Colleges is designed to better utilize our soil resources and to improve their management, in order that each acre may contribute more effectively to the Nation's agricultural production. This and other land-use and conservation programs have caused changes in the pattern of fertilizer consumption by crops in recent years.

The use of fertilizer on major crops in certain years of the period 1929 to 1950 is shown in table 5. In 1929 cotton received 28 percent of the fertilizer used in the continental United States, and hay only 2.1 percent. The quantity applied to grass is not known but was very small. By 1949-50, the portion used on cotton had dropped to 9 percent, while that used on hay and pasture had increased to 5.2 percent and 7.2 percent, respectively. During the same period the trend in the proportionate use of fertilizer on corn and small grains was definitely upward, but the opposite was true for tobacco and potatoes.

## CONSUMPTION OF AGRICULTURAL LIME

Use of agricultural liming materials in the United States has increased greatly since 1935 (table 6). The agricultural conservation program of the U. S. Department of Agriculture has been a major factor influencing this increase.

The total consumption of liming materials in 1950 was 29.8 million tons, or 9 times that in 1935. Of the total quantity in 1950, 70 percent was used in the North Central and 11 percent in the South Atlantic States. Among the individual States, Illinois ranked first and Missouri second, with respective consumptions of 16 percent and 13 percent of the national total. On the other hand, North Carolina and Georgia—top-ranking users of commercial fertilizer—used only about 3 percent and 1 percent, respectively, of the national consumption of agricultural liming materials.

Use on pasture accounted for 16 percent of the total farm consumption of agricultural lime in 1947. Of the consumptions in the different regions the proportion of such use ranged from less than 1 percent in the Northern Plains to 51 percent in the Delta States. It was 8.5 percent in the Pacific and the Corn Belt and Lake States, 17 percent in the Northeast, about 42 percent in the Southern Plains and Appalachian States, and 48 percent in the Southeast.

## LIQUID FERTILIZERS

Formerly, commercial fertilizer materials were entirely in the form of solids. Today, however, large quantities of liquid products are used. Among these products, anhydrous ammonia and its preparations are by far the most important. Other liquid products include phosphoric acid, foliage sprays, and mixed fertilizers.

Following the establishment on a large scale of the domestic synthetic ammonia industry in 1921, ammonia became the cheapest source of nitrogen, and attention was soon given to its utilization directly as a fertilizer material. Ammonia is a gas at ordinary temperatures and pressures, but customarily is marketed either as liquid anhydrous ammonia or in aqueous solution.

Because of the acidic properties of superphosphate, the major constituent of most mixed fertilizers, it was found possible to add directly to the mixtures substantial percentages of free ammonia in various liquid forms, including aqueous solutions of ammonia with nitrogen salts such as ammonium nitrate and urea. Use of ammonia in this way rapidly became an established practice in the fertilizer industry. More than 300,000 tons of nitrogen in liquid form are now used annually in the domestic manufacture of mixed fertilizers.

Anhydrous ammonia—containing, as it does, some 82 percent of nitrogen—is the most concentrated form of plant-nutrient nitrogen. This fact, together with its relatively low initial cost per unit of nitrogen, caused attention to be given to its direct use as a fertilizer.

Practical application of anhydrous ammonia through the medium of irrigation water was initiated in California in 1934 by an ammonia-manufacturing company. This method of using ammonia has given excellent agronomic results and is widely practiced in the West.

Through the efforts of the Mississippi Agricultural Experiment Station, use of anhydrous ammonia by direct injection into the soil came into practice in Mississippi in 1947. Subsequently, such use of ammonia has spread to more than half of the States in the Union, and it accounts for at least 8 percent of our present consumption of fertilizer nitrogen.

It is expected that use of anhydrous ammonia for direct application to the soil will continue to expand, especially in those areas where the size of the fields, soil conditions, farming practices, requirements for plant nutrients, and other factors are such that nitrogen in this form can be placed in the soil at a lower unit cost than nitrogen in other forms.

One of the prerequisites to an expansion in the agricultural use of anhydrous ammonia is adequate storage capacity. The industrial users of anhydrous ammonia purchase on a monthly delivery basis the year around; this permits steady movement of the ammonia from the manufacturing plant. Fertilizer, on the other hand, is used chiefly in the March-July period, which necessitates storage of much of the material for a considerable period of time. For anhydrous ammonia to maintain a favorable position as a material for direct use as fertilizer, it is essential that facilities be provided for local storage of at least half of the total quantity required during the fertilizer year. This should result in more favorable contracts for ammonia, since it will permit off-season shipments and will lessen the strain on transportation facilities during the fertilizer season itself. Also, it will better assure that the farmer receives the material when needed.

The storage may be on individual farms, provided the quantities of ammonia involved are such as to justify the expense of installing and maintaining the facilities. In general, however, bulk-distribution stations—centrally located with respect to relatively small areas of consumption—will be more practical and economical.

Large quantities of liquid phosphoric acid are used in the production of triple superphosphate and the ammonium phosphate fertilizers. Although its use for these purposes is presently confined almost entirely to plants coexistent with the acid-making facilities, there is some sale of phosphoric acid for fertilizer manufacture.

Table 7. - Relation of expenditures for fertilizers to total agricultural production expenses of farm operators and to farm income in the previous year, United States, 1911-1949

| Calendar year | Total production expenses 1/ | Cash income from crops and government payments 2/ | Expenditures for fertilizers: Amount | Expenditures for fertilizers: Portion of - Production expenses | Expenditures for fertilizers: Portion of - Previous year's income |
|---|---|---|---|---|---|
| | Million dollars | Million dollars | Million dollars | Percent | Percent |
| 1911 | 3,646 | 2,925 | 159 | 4.4 | 5.4 |
| 1912 | 3,890 | 3,111 | 153 | 3.9 | 5.2 |
| 1913 | 4,035 | 3,095 | 172 | 4.3 | 5.5 |
| 1914 | 4,120 | 2,920 | 197 | 4.8 | 6.4 |
| 1915 | 4,223 | 3,280 | 159 | 3.8 | 5.4 |
| 1916 | 4,845 | 4,043 | 165 | 3.4 | 5.0 |
| 1917 | 6,136 | 5,660 | 218 | 3.6 | 5.4 |
| 1918 | 7,558 | 6,985 | 297 | 3.9 | 5.2 |
| 1919 | 8,461 | 7,674 | 326 | 3.9 | 4.7 |
| 1920 | 9,130 | 6,654 | 359 | 3.9 | 4.7 |
| 1921 | 6,875 | 4,199 | 203 | 3.0 | 3.1 |
| 1922 | 6,826 | 4,321 | 193 | 2.8 | 4.6 |
| 1923 | 7,125 | 4,885 | 200 | 2.8 | 4.6 |
| 1924 | 7,495 | 5,415 | 210 | 2.8 | 4.3 |
| 1925 | 7,464 | 5,526 | 229 | 3.1 | 4.2 |
| 1926 | 7,505 | 4,889 | 227 | 3.0 | 4.1 |
| 1927 | 7,545 | 5,157 | 205 | 2.7 | 4.2 |
| 1928 | 7,855 | 5,044 | 267 | 3.4 | 5.2 |
| 1929 | 7,780 | 5,125 | 268 | 3.4 | 5.3 |
| 1930 | 7,059 | 3,840 | 264 | 3.7 | 5.2 |
| 1931 | 5,634 | 2,536 | 184 | 3.3 | 4.8 |
| 1932 | 4,574 | 1,997 | 113 | 2.5 | 4.5 |
| 1933 | 4,374 | 2,604 | 118 | 2.7 | 5.9 |
| 1934 | 4,727 | 3,450 | 141 | 3.0 | 5.4 |
| 1935 | 5,111 | 3,551 | 160 | 3.1 | 4.6 |
| 1936 | 5,581 | 3,938 | 160 | 2.9 | 4.5 |
| 1937 | 6,126 | 4,315 | 208 | 3.4 | 5.3 |
| 1938 | 5,744 | 3,672 | 182 | 3.2 | 4.2 |
| 1939 | 6,088 | 4,173 | 218 | 3.6 | 5.9 |
| 1940 | 6,484 | 4,237 | 223 | 3.4 | 5.3 |
| 1941 | 7,469 | 5,302 | 250 | 3.3 | 5.9 |
| 1942 | 9,465 | 7,028 | 301 | 3.2 | 5.7 |
| 1943 | 10,882 | 8,652 | 373 | 3.4 | 5.3 |
| 1944 | 11,640 | 9,842 | 400 | 3.4 | 4.6 |
| 1945 | 12,629 | 10,307 | 440 | 3.5 | 4.5 |
| 1946 | 14,238 | 11,937 | 521 | 3.7 | 5.1 |
| 1947 | 16,849 | 13,910 | 581 | 3.4 | 4.9 |
| 1948 | 18,545 | 13,725 | 655 | 3.5 | 4.7 |
| 1949 3/ | 18,038 | 12,922 | 698 | 3.9 | 5.1 |

1/ Includes livestock industry.

2/ Excludes livestock industry.

3/ Preliminary

U. S. Department of Agriculture

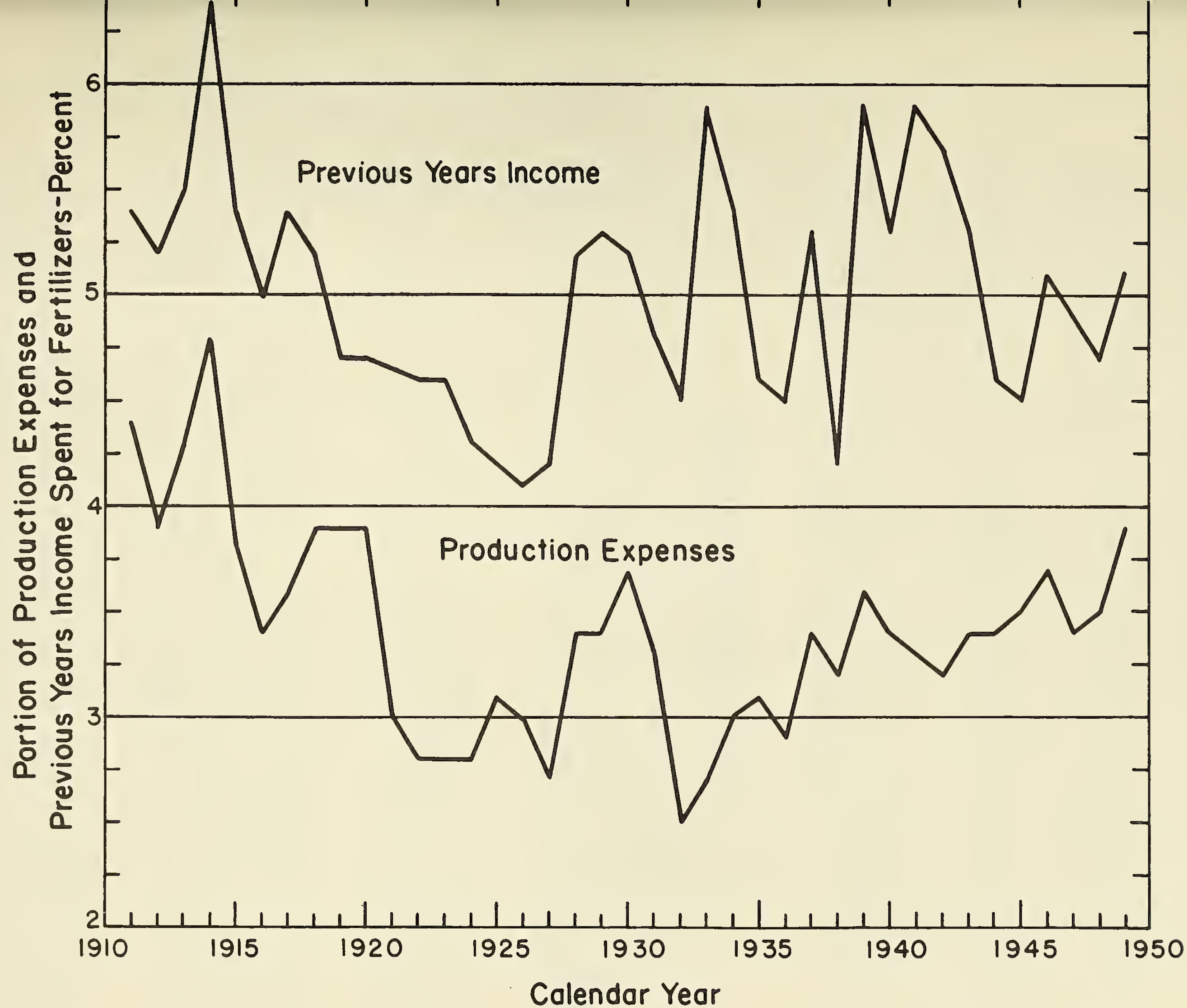


Figure 3. - Relation of expenditures for fertilizers to total agricultural expenses of farm operators and to farm cash income from crops and Government payments in the previous year, United States, 1911 - 1949.

Direct use of liquid phosphoric acid as a fertilizer is practiced on a limited scale in the West, chiefly by addition to irrigation water. Application of the acid directly to the soil also is receiving some attention.

Deficiencies of some of the trace elements, such as copper, zinc, iron, and manganese, are often remedied most effectively and economically by foliage-spray applications of their compounds.

For various reasons, foliage-spray applications of the primary plant nutrients have been generally limited thus far to nitrogen compounds for a few kinds of plants. An important example is the spraying of apple trees with urea solutions.

Liquid mixed fertilizers are used to a limited extent for direct application to the soil and for addition to irrigation water, chiefly in the West. Fertilizer solutions are commonly used throughout the country in the transplanting of vegetable crops.

## EXPENDITURES FOR FERTILIZERS

In 1949 the farmers of the United States spent nearly 700 million dollars for fertilizer, or 4.4 times the expenditures in 1911. Likewise, the total agricultural production expense of farm operators, including the livestock industry, was 4.9 times as great in 1949; the farm cash income from crops and Government payments, excluding the livestock in industry, was 4.4 times as great. The relationships are shown in table 7 and figure 3.

The total expenditure for farm fertilizer in 1949 was 3.9 percent of the total agricultural production expense of farm operators in that year. The proportion fluctuated relatively little during the period 1911 to 1949. It ranged from 2.5 to 4.8 percent and averaged 3.4 percent.

Throughout the period 1911 to 1949 the total annual expenditure for fertilizer by the Nation's farmers showed a close relationship with the farm income in the previous year. As would be expected, the relation is much closer for the income from crops than the income from livestock. Farm income from Government payments is also related to fertilizer use, because a part of such payments is for conservation practices involving the use of fertilizers.

From 1911 to 1949 the national annual expenditure for farm fertilizer has averaged 5 percent of the farmers' cash income in the previous year from crops and Government payments, exclusive of the livestock industry. In only 11 years of the period was the proportion less than 4.5 percent or more than 5.5 percent. It ranged from 3.1 percent in 1921 to 6.4 percent in 1914.

The proportion of the income spent for fertilizers varies greatly among the States and regions. It is generally much higher in the older fertilizer-consuming States than in the newer areas of use. In South Carolina, for example, it has averaged about 19 percent for many years. In Texas and Minnesota, on the other hand, the proportion has increased from zero in 1900 to about 1 percent at present. Also, the relation shows a very definite upward trend in a number of other States where the use of fertilizer is expanding markedly.

Although the percentage of income spent for fertilizer in the Nation as a whole has been remarkably constant for many years, it can be expected that for the future the trend will be upward. This is because of the rapidly growing realization of the importance of fertilizers in crop production and in the maintenance and improvement of soil fertility, as reflected by the great increase in fertilizer consumption during the past few years.

## FERTILIZER APPLICATION AND PLACEMENT

Fertilizer placement with respect to seed and plant is a very important factor in crop stands and yields and in fertilizer efficiency. It was not until after World War I, however, that major attention was given to the problem. The growing trend toward higher-analysis fertilizers served to emphasize the need not only for better uniformity in the application of fertilizers and their most accurate placement in the soil but also for the development of better fertilizer-distributing machinery.

The complexity of the problem is such that no simple solution is possible. The rates of fertilizer application range from as little as 25 pounds per acre to a ton or more. For optimum results, the placement of the fertilizer varies with different crops. Fertilizers differ greatly in their physical properties and their plant-nutrient content. They comprise compressed gases—such as liquid anhydrous ammonia—which must be handled in high-pressure equipment, aqueous solutions, highly hygroscopic salts such as ammonium nitrate, and other solid materials that vary widely in particle size and drillability. The concentration of plant nutrients in fertilizers ranges from less than 20 percent to more than 80 percent.

Despite the many complications, important advances have been made in the techniques and equipment for the application and placement of fertilizers since the days when the materials were distributed mostly by hand. A continuing program of research and development must be carried on, however, to effect further improvements and to keep abreast of the changing requirements of modern agriculture. A highly important phase of the problem relates to the improvement of the physical condition of solid fertilizers, as by granulation, better sizing of the particles, and other means.

There are five general methods of applying fertilizer. These are (1) broadcasting before seeding, (2) drilling in narrow bands before or at time of seeding, (3) applying in hill or row at time of planting row crops, (4) top dressing or side dressing while the crop is on the ground, and (5) applying fertilizer at time of plowing.

Machines of numerous types and sizes are now on the market for applying fertilizers by the different methods to the various crops under widely varying conditions and practices. Separate machines solely for applying fertilizers include simple hand-operated devices, push-type distributors, horse-drawn single- and multiple-row distributors and broadcasters, and pull-type machines for both tractors and trucks. Fertilizer drilling and spreading attachments are mounted on plows, cultivators, disk harrows, seed drills, planters, transplanters, manure spreaders, wagons, trucks, tractors, and airplanes. Equipment for applying liquid fertilizers includes spreading machines, implement and tractor attachments, sprayers, and metering devices for use with irrigation systems.

Many different types of soil-furrowing tools and other fertilizer-placement devices are used, and there is considerable variation among them as to the manner in which the fertilizer is deposited in the soil and as to the location of the fertilizer with respect to the seed or transplanted seedling.

On the basis of more adequate research data in recent years, fertilizer equipment on a number of machines has been improved in design. Many machines now place the fertilizer in accordance with recommendations for the specific crops or conditions that are involved.

Bulk distribution of fertilizers from the plant, storage depot, or freight car directly to the soil, on a custom basis, has recently come into considerable practice in some parts of the country. Such practice is much more extensive with liming materials. The fertilizers handled in this way comprise chiefly anhydrous ammonia, ground phosphate rock, superphosphate, and mixed fertilizers.

A recent innovation, as yet practiced on a very limited scale, is the manufacture of mixed fertilizers in plants so designed that the material is delivered directly from the mixing unit into spreader trucks for transportation to the farm and application to the soil. It is understood that such distribution of mixed fertilizers is presently confined mostly, if not entirely, to broadcast applications chiefly to pastures, legumes, and small grains. Since the cost to the farmer of fertilizer mixed and distributed in this way is reported to be less than that by the customary procedure, the practice can be expected to increase. Aside from the lower cost, it has the advantage that the problem of poor physical condition of the fertilizer is greatly reduced because storage is eliminated.

Experiments are being made with fertilizer distributors having several compartments from which the delivery of the respective materials can be effected at different rates. Perfection of such distributors would permit the simultaneous application of nitrogen, phosphate, potash, and other plant-nutrient materials without the need for compounding them into mixed fertilizers.

Use of the airplane for broadcast distribution of fertilizer is a new and fertile field for research and development.

## II. FACTORS INFLUENCING THE QUANTITIES OF FERTILIZER APPLIED, AND ECONOMIC LEVELS OF FERTILIZER USE

### FACTORS INFLUENCING THE USE OF FERTILIZERS

#### GENERAL FACTORS

The use of fertilizer is one of many ways in which crop yields and total agricultural production may be materially influenced. The influence of fertilizer alone is difficult to segregate, but the effect of varying the combination of fertilizer with other production factors can be measured. The farmer's choice as to which of the many possible combinations of alternatives he will use is made on the basis of his judgment as to their relative profitability. Comparative responses in yields and relative costs of the different combinations determine the final choice of alternatives, provided the farmer is well informed as to these matters.

There is not only a problem in the choice of alternatives but also in determining the extent of use of the combination finally chosen. In each combination, there may be certain practices that are fixed in this respect--they are either done or are not done. But other practices, like the use of fertilizer, may be varied. If the farmer had complete information as to the response to be obtained from using more fertilizer at different levels of other practices, he would combine more and more fertilizer with these other practices until the last increment just paid its way. But lack of such information is perhaps one of the most important factors retarding the use of fertilizers. Otherwise, more fertilizer would generally have been used, so as to increase the yields to about the point where financial returns from the fertilizer applied were about equal to the cost of fertilizer and other expenses associated with use of more fertilizer. Except for selected crops in certain areas, farmers have generally used much less fertilizer than would have been most profitable.

The physical factors that influence the use of fertilizer include soil characteristics that favor or limit the plant response, the crops grown, the type of farming, and climatic conditions. Some soils are relatively unproductive even when fertilized. The types

of crops grown and the market demand are very important factors. Crops that have high unit values, such as vegetables, and that also respond well to fertilizer, receive the heavier applications. Some such crops are highly seasonable, and the use of fertilizer permits getting them to market at a time when prices are highest. The type of farming, the balance between feed-crop and cash-crop production, and the relative importance of livestock in the farming system, all influence the quantity and kind of fertilizer used. However, type of farming is in turn largely determined by soil and climatic factors, so its influence on fertilizer use is partly of an indirect nature.

Improvements in balance and flexibility of farming systems, such as are now taking place in the South, may have a profound effect on future use of fertilizers. Developments in improved pastures and other feed crops, as a base for expanded livestock operations, may greatly influence the quantity and kind of fertilizer applications that may be expected in going from primarily cotton to cotton-livestock systems of farming. But in the Corn Belt, for example, phosphate has been the principal fertilizer applied to balance the more ample supplies of nitrogen and potash contained in the soil and in livestock manure, for production of legume hay and pasture crops. Thus, the fertilizer and manure have been incorporated in a rotation including corn (also soybeans) and small grains. In recent years, however, there has been a rapid increase in the use of both nitrogen and potash fertilizers in the Corn Belt. Much of this increase has taken place because of the depletion resulting from long-continued cropping and erosion losses of soil fertility.

Gains in the use of improved conservation and land-management practices will undoubtedly influence the future use of fertilizer. Thus far, these gains have been accompanied by large increases in the use of all plant nutrients. Indeed, proper use of fertilizer is, itself, a major conservation practice. Even when the fertilizer is not applied directly to hay or pasture, these crops benefit from applications made to other crops in the rotation. Applications of fertilizers result in the return of greater quantities of crop residues to the soil, and thus can help to maintain and improve the organic-matter content, structure, and moisture-holding capacity of the soil. Maintenance of these soil factors at high levels is conducive to better productivity and permits greater crop-yield responses when fertilizer is applied. Drainage of water-logged soils also adds to the land area on which profitable crop response may be obtained when fertilizer is used. Thus, so long as market demands permit, improved conservation and land-management practices create conditions whereby the point of marginal returns from fertilizer is extended.

Farmers tend to make comparable changes in other practices as they increase their use of fertilizers. Of course, new technological developments sometimes introduce new opportunities so that some new practice is expanded rapidly. Some practices, such as use of hybrid seed corn, cost so little more in relation to clearly visible results that their adoption more nearly approaches 100 percent than in the case of many others. Even though the cash cost of a practice—for example, contouring—may be negligible, the "effort" cost or the break it represents from the traditional way of doing things may be such that increase in the extent of its adoption may be relatively slow. Many of the so-called conservation practices fall in this category, so that gains in their use will likely be kept in balance with increases in the use of fertilizer. Therefore, even in the long run, improvements in conservation practices will likely go hand in hand with increases in the use of fertilizer, even though it is recognized that a given quantity of production might be maintained by carrying many of the other practices at higher levels without increasing applications of fertilizer.

## SECONDARY AND TRACE ELEMENTS

Calcium, magnesium, sulfur, and the so-called trace elements (boron, copper, manganese, and zinc) are necessary for normal plant-growth. Many of our soils are deficient in these elements. Response to calcium and magnesium in the form of liming materials is measured most directly in terms of forage production, principally legumes. But cultivated crops also are benefited. Most of this benefit is of an indirect nature as a result of growth of legume crops which add some nitrogen to the soil and which, because of the nature of their root growth, also make native fertility more available. Many legumes are heavy users of lime. Also some lime is lost through leaching. A program of repeated liming at appropriate intervals is necessary to maintain desirable systems of farming in those areas where the addition of lime is essential. In many areas, certain legumes that form an important part of the feed and pasture supply cannot be grown without the use of lime.

Most crop plants require large amounts of calcium, magnesium, and sulfur for normal growth and development. Although some soils initially contained adequate supplies of these elements, their addition to the soil is becoming increasingly necessary. Large quantities of calcium are supplied by superphosphates and limited quantities of both calcium and magnesium are furnished by the dolomite included in neutral fertilizers. The calcium status of soils should be maintained by adequate liming practices, using dolomitic limestone where the magnesium content of the soil is low. In general, the sulfur requirement of crops has been adequately supplied by normal superphosphate and ammonium sulfate. Further, rainwater throughout the industrial

part of the country brings down ten or more pounds of sulfur per acre per year. As the use of high-analysis phosphates increases, more attention must be given to meeting the sulfur requirements of plants.

Plants also require small quantities of boron, zinc, copper, and manganese for normal growth and nutrition. Soils vary greatly in their original mineral makeup and in their ability to supply adequate quantities of these elements. Sandy soils and the Everglades of Florida constitute major areas of trace-element deficiencies. Scattered deficiencies of one or more of these elements have also been encountered throughout the eastern coastal plains and in other parts of the country. Corrective applications average only 10 to 30 pounds of zinc, copper, or manganese sulfate, per acre and from 5 or 10 pounds of borax up to 60 or 80 pounds for such crops as beets and alfalfa. From 5 to 20 pounds of borax per ton is now being included in certain mixed fertilizers marketed in the eastern seaboard area.

## OTHER FACTORS

In general, the efficiency of the use of mixed fertilizers is as great or greater than the separate use of the constituent materials. There is little difference in the efficiency of the various potash materials. For most crops, chemically processed phosphates are far more efficient than ground raw phosphate rock. Direct application of phosphate rock promises economic returns for forage production on acid soils, where a large increase in the phosphate level of the soil is required. There is a wide range of nitrogen fertilizer sources, generally of approximately equal value. The major exception is low-grade organic materials, which may be only half or less as efficient as the soluble nitrogen compounds. There are conditions where the ammonia forms reduce leaching losses and where the nitrate forms are more readily utilized by crops. For the most part, however, soluble nitrogen materials have the same value per unit of nitrogen in raising crop yields.

Technological developments in fertilizer production are discussed in other sections of this report. These developments will tend to increase the amounts of fertilizer that can be used economically. There has been a steady increase in the plant-nutrient concentration of fertilizers, and granulation of mixed fertilizer will make further increases possible. Omission of conditioning agents will enable the inclusion of more pounds of N, $P_2O_5$, and $K_2O$ per ton, with consequent reduction in costs for freight, bagging, and handling.

Use of larger quantities of triple superphosphate will also make possible higher-analysis mixed fertilizers. Two attendant

problems will be meeting the sulfur needs of crops, and a more critical adjustment of rates and placement to prevent germination and seedling injuries by the more concentrated fertilizers.

Fertilizer application and placement techniques have improved greatly during the last two decades. For most row crops, satisfactory fertilizer-placement equipment is available. Proper placement prevents germination injury, yet places the fertilizer in a position of ready availability to the crop early in its development, and at the same time reduces soil-fertilizer reactions. The future will see improvement in fertilizer-placement equipment for sugar beets and cotton, and considerable research is now in progress on techniques of fertilizer placement for hay and pasture seedings. These studies can be expected to yield still further benefits in increasing the efficiency of fertilizer use.

Fertilizer use is but one of a series of interrelated soil- and crop-management practices. Satisfactory returns from fertilizers are dependent on good seed, proper equipment for land preparation and cultivation, and the control of insects and diseases. Similarly, adequate soil moisture, proper plant spacing, and timeliness in farm operations are all essential for a sound production program. Current fertilizer-use studies reveal that individual practices, such as changing spacing, or crop varieties, or fertilization, may separately yield little or no return, but that optimum combinations of such soil- and crop-management variables can be fitted into management systems with outstanding results. American agriculture is continually taking advantage of more and more of these combinations of practices, as the relationships involved are being worked out.

## ESTIMATES OF CURRENT YIELD RESPONSE TO VARYING RATES OF FERTILIZER USED ON MAJOR CROPS IN SELECTED AREAS

It is difficult to estimate the economic level of use of fertilizer, because relatively little data are available covering a range of application that is adequate for this purpose. Some experiments dealing with a single nutrient provide adequate data applicable to local conditions. But the basis for a thorough economic interpretation involving different combinations of all three of the primary plant-nutrients and applicable generally to major areas of production is quite limited. However, some estimates of yields associated with rates of application that are much higher than those usually practiced but are well below the levels

that would be most profitable under optimum conditions, are presented in this section. These estimates, in turn, are developed from some estimated State-average curves of response. 1/

Corn furnishes, perhaps, the most outstanding example of the opportunity for progress in closing the gap between current and potential production through use of more fertilizer. General increases in the yield of corn could be made although there is considerable regional variation. Additional phosphate is most important in the Corn Belt and adjoining States, while in the South and Southeast the major limiting factor is nitrogen. The highest rates of fertilizer application on corn are made in the Northeast, where nitrogen and potash are of somewhat more importance than phosphate in increasing yields. Even though little fertilizer is used on corn in the West, yields could be nearly doubled through increased applications--primarily nitrogen, either alone or in combination with phosphate in some instances. Relatively smaller increases in yield would be obtained through use of additional fertilizer on crops now being fertilized at high rates per acre. These include primarily tobacco, potatoes, and vegetables. But for corn, small grains, other field crops, and hay and pasture the opportunity for increasing yields is very great and current rates of application are far short of what would be most profitable even at current levels of other practices.

The estimates presented in this section are in terms of somewhat lower rates than would be most profitable and lower yields than would be theoretically attainable. The estimates were developed within the frame-work of a general index of crop prices of 300, 1910-1914 = 100. A general fertilizer price index of 165 was used, slightly higher than current. Current price relations of about 2.7 to 1.38 to 1.0 per pound of N, $P_2O_5$, and $K_2O$, respectively, were used. In the calculations, allowance was made for the cost of applying the fertilizer and for the cost of harvesting and marketing the additional yield.

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1/ Estimates of separate yield responses to N, $P_2O_5$, and $K_2O$ were made for all major crops and for pasture by agronomists in all States, under direction of the National Soil and Fertilizer Research Committee, including members of the soils research staff of the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture. Estimates of economic levels of fertilizer use were developed in the Division of Farm Management and Costs, Bureau of Agricultural Economics, U. S. Department of Agriculture.

## FERTILIZER ON CORN IN THE CORN BELT

Approximately one-fourth of all commercially produced plant nutrients used on all crops in the United States is applied on the corn crop. For the Corn Belt and Lake States the proportion of all nutrients used that is applied on corn approaches 40 percent. More than one-third of the nutrients used on corn in the United States is represented by applications to the corn crop in these States. Curves of the estimated response of corn to plant nutrients in Iowa are used as the basis for this discussion.

The current average yield of corn in Iowa is about 49 bushels per acre, and only about 8 pounds of commercial plant nutrients are applied per planted acre. However, about 23 pounds are applied per acre fertilized. Estimates of the most profitable rates of application and of yields at those rates must be thought of in terms of stated levels of other yield-influencing practices. Higher rates would be profitable if other practices are carried out at optimum levels instead of at current levels. Preliminary calculations indicate that if farmers improved other practices about 50 percent over current levels, and applied about half as much fertilizer as would be most profitable at such levels of other practices, the yield would be about 60 bushels per acre and the application might be from 40 to 50 pounds of nutrients per acre. The increase in yield would be somewhat above 20 percent. Nearly doubling of the above rates might be profitable in situations where other practices were carried to optimum levels, and in such cases the yield could be expected to approach 75 bushels per acre. Inclusion of more legumes in the rotation should lower the rate at which nitrogen would be most profitable.

## FERTILIZER ON COTTON IN THE PIEDMONT

About 10 percent of all plant nutrients used on crops and pasture in the U. S. is applied on cotton. Curves for an Appalachian State, North Carolina, are used here to illustrate the response of cotton to fertilizer in the Piedmont region.

Lower rates of application would have a much greater effect in reducing yields of cotton than in the case of corn in the Corn Belt States. If no fertilizer were applied the average yield for North Carolina would be expected to drop to about 450 pounds of seed cotton, equivalent to about 157 pounds of lint, at current levels of other practices. Continued reduction in the rates of application would, of course, reduce yields much more than that.

The 1949 average yield of seed cotton in North Carolina was about 729 pounds. About 112 pounds of commercial plant nutrients were applied per planted acre, but a very high percentage of the

acreage is now being fertilized. Estimates thus far developed indicate that use of approximately 150 pounds of plant nutrients, in conjunction with a 50 percent improvement in other practices might result in a yield of about 1,250 pounds of seed cotton. As in the case of corn, or of most other crops, increased fertilization of cotton and improvements in other practices are likely to take place more or less together. Probably from 200 to 300 pounds more could be added to the yield if the most profitable rate of fertilizer application appropriate to a 50 percent improvement in other practices, were used.

Current yields of seed cotton in North Carolina are about 34 percent of the maximum attainable yield with other practices at optimum levels, but are about two-thirds of the potential yields at current levels of other practices.

## FERTILIZER ON HAY AND PASTURE IN THE NORTHEAST

About 11 percent of all plant nutrients are applied on hay and pasture in the United States. The comparable figure for the Northeast is about 13 percent. Estimated response of legume-grass hay and pasture to fertilizer in New York indicates that the current average yield is little more than one-third the yield that could be obtained by going half way toward the most profitable rates of application and making a 50 percent improvement in other practices. This would mean an application of about 100 pounds of plant nutrients per acre. A very small percentage of the acreage now receives an application that approaches this rate. At this rate and at current price relationships the most profitable ratio of N, $P_2O_5$, and $K_2O$ would be approximately 1.0-3.5-3.5. Where fertilizer is used on hay and pasture, several times as much phosphate is now being applied in relation to nitrogen, than is indicated by this ratio. The estimated curves of response to N, to $P_2O_5$, and to $K_2O$, together with current price relationships for these nutrients, indicate that the current fertilizer practice on hay and pasture could be improved materially, both as to the quantity applied and the plant-nutrient ratio.

## FERTILIZER ON VEGETABLES IN THE APPALACHIAN STATES

Vegetable crops receive about 11 percent of the three primary plant nutrients applied on farms in the United States. Rates per acre are exceeded only by those on potatoes, tobacco, and fruit crops. There is considerable regional variation in the rates. Curves of yield response to varying rates of fertilizer on vegetables in North Carolina are used here for illustrative purposes. Varying responses are indicated by the curves from States in other regions.

Using the same approach as for the other crops, it appears that the current rate of application represents an intermediate level, or considerably less than the most profitable rate. However, the calculated intermediate rate indicates that considerably more nitrogen but less phosphate and potash would be a more profitable combination. Making this shift in the fertilizer combination and improving other practices by 50 percent would probably increase the yield of vegetables by more than 25 percent. The State average yield of fresh and processing vegetables in 1949 was a little over 5,000 pounds per acre, and the above-indicated shift in fertilizer use and other practices would probably result in a yield of a little more than 6,500 pounds. This is considerably short of the maximum that could be obtained in individual instances, as a result of applying the rates that would be most profitable if other practices were improved to potimum levels.

## GENERAL PRODUCTION LEVEL ASSOCIATED WITH THE MOST PROFITABLE RATES OF APPLICATION

In the preceding sections, illustrations were presented showing the effect of varying rates of application of fertilizer on yields of a few major crops in selected States. Estimates were made of the yields per acre that would be associated with stated rates of application in conjunction with comparable improvements in other practices. An estimate of the effect of such rates on the total volume of crop and pasture production in the United States is presented in this section.

Average response to four major crops, each in a selected State, was used as the basis for estimating the total quantities of plant nutrients required and the total production that would result from application of the most profitable rates. These crops--corn, cotton, vegetables, and hay and pasture--accounted for nearly 60 percent of the total farm use of the three primary plant nutrients in 1950. The curve of response for each of these crops for a single State was assumed to be representative of that crop for all States, i.e., yields per acre at various rates of plant nutrients were multiplied by the total U. S. acreage of that crop. Average response was calculated by obtaining the dollar value of production of each crop at the different levels. These were then added and expressed as a percentage of the current value of production of these crops. Allowance was made for crops and areas where experience has shown little or no response to fertilizer, so that the relative production calculated at different rates of application reflects appropriate weighting of these non-responsive crops and areas. It is emphasized that the estimates of over-all use of plant nutrients and of resulting production at different rates of application are to be regarded as preliminary and subject to substantial revision upon more thorough evaluation.

The most profitable rates of application, where adopted at optimum levels of other practices, would correspond to about 10 times the current total use of the three primary plant nutrients. If other yield-influencing factors were improved commensurately, such rates applied to the four crops used in this analysis might result in a total production of nearly three times that now being attained. These estimates represent the absolute limits of plant-nutrient use and of crop and pasture production under the price and cost relationship indicated. Obviously, such results are unattainable as national totals, although a few of the more progressive farmers may attain comparable results in special instances. A more probable result, assuming that demand conditions remain sufficiently favorable, would be something approaching a half-way mark, both with respect to rates of plant-nutrient application and to levels of other practices. Even this combination of improved practices, in conjunction with four to five times the current use of plant nutrients, would probably result in a production approximately double that now attained. If such an estimated increase seems large, it must be emphasized that a very substantial portion would be attributable to improvement in practices other than the increased use of fertilizer. The implications of such a volume become apparent when reviewed in the light of estimated production needs by 1975, which according to certain estimates, will be approximately 40 percent above current production levels.

About 4-1/2 million tons of plant nutrients were used in the United States in the year 1950. The plant-nutrient ratio of this tonnage was 1.0 to 1.8 to 1.1 for N, $P_2O_5$, and $K_2O$, respectively. At the most profitable levels—about 10 times this amount—the average plant-nutrient ratio for the three cultivated crops used in developing the estimates would be about 1.0 to 1.1 to 1.2. At an intermediate level of application the most economic combination would include relatively a little more phosphate and potash.

The nutrient ratio for hay and pasture differs markedly from that for most cultivated crops. Estimates of total use of fertilizer on hay and pasture in the United States indicate a plant-nutrient ratio of about 1.0 to 14.5 to 2.5. Response curves for hay and pasture in New York, used as the basis for developing the preliminary estimates of most profitable rates, indicate that at such rates the most economic nutrient ratio would be about 1.0 to 2.3 to 2.5. At the intermediate rate the optimum combination would call for relatively more phosphate and potash, but still a markedly different ratio than is reflected by current use.

## III. ESTIMATED QUANTITIES OF FERTILIZER AND RELATED MATERIALS ASSOCIATED WITH PRODUCTION LEVELS OF 1975

### NITROGEN, PHOSPHORIC OXIDE, AND POTASH

The large increases in production that would result from much greater use of fertilizer indicate the need for considering a balanced production program. Gains will surely be made with reference to other known practices. Furthermore, over a period of 25 years, important new, unforeseen developments will no doubt occur. Therefore, the quantities of fertilizer needed to support estimated production levels 25 years hence will depend not only on the extent to which there is further adoption of other known practices but also on new developments in farm technology.

If past relationships between increases in farm output and increases in the use of fertilizer are projected toward a further increase of 40 percent in output, the associated tonnage of plant nutrients would be more than 2.5 times the current levels. This tonnage is approximately equal to that required to obtain such an increase in output when calculations are based on the estimated response curves for the four crops, with other practices remaining at current levels.

However, the balance between use of additional fertilizer and improvements in other practices is a matter of conjecture. Adoption of all practices, including use of fertilizer, follows successful experience. Fertilizer properly used results in more-or-less spectacular increases in yields. In recent years, plant-nutrient consumption has increased at an average annual rate of about 10 percent. If this rate is projected for 20 years, the quantities used by that time would be four times those used now. But even with no improvement in other practices, such a level of use might result in nearly a 75 percent increase in farm output. If the response were that great, and if it develops that a healthy economic balance would be reached with a 40 percent increase in output, it appears unlikely that the use of fertilizer will reach this level.

However, substantial changes in farming systems could slow down the rate of increase in output that is obtained when stated quantities of fertilizer are added. Percentage-wise, the response of hay and pasture to fertilizer is less than that of most cultivated crops. Development of hay and pasture on a large scale will require more fertilizer to obtain a given increase in output, so that what happens along this line will have a substantial effect on the quantity of fertilizer that could be used profitably in a balanced economy by 1975. Soil depletion through heavy cropping and erosion brings about a need for use of more fertilizer in some areas. Estimation of such effects is difficult. Soil-forming processes add slowly to the stock

of available plant nutrients. Systems of farming greatly affect the physical productivity balance. But if "grassland agriculture" becomes more prevalent, the fertilizer needed to establish and support such a system will be greater than would be required to offset normal depletion resulting from existing systems. However, the effect of depletion would be to require more fertilizer than would otherwise be estimated as necessary to maintain a given level of output.

Depending upon future developments as to farming systems and on technical progress in all practices, it is quite conceivable that consumption of plant nutrients could range anywhere between about 10 million and 14 million tons by 1975, with a farm output about 40 to 45 percent higher than the current level, assuming the price-cost relationships projected in this study. It hardly seems probable that a plant-nutrient consumption of four times the current level will occur, unless the farm output is expanded to a greater extent than is now anticipated.

The distribution of plant nutrients as to N, $P_2O_5$, and $K_2O$ will also depend on the nature of the changes in farming systems and on technological developments in the manufacture and use of fertilizers. Developments as to price relationships between the three nutrients will influence the nutrient ratio that would be most profitable. Substantial increases in the use of fertilizer on hay and pasture would mean the use of more phosphate and potash, relative to nitrogen, than would otherwise be the case.

## SECONDARY AND TRACE ELEMENTS

The use of agricultural liming materials is well below current needs and should be increased sharply. From 1920 to 1935 the use of liming materials was at a rate of less than 5 million tons per year. Subsequently, under the impetus of Federal conservation programs, the annual use has increased to 25 to 30 million tons. A large tonnage is required just to maintain a satisfactory lime status on lands that have been limed. Maintenance and improvement of the lime status of agricultural soils in this country would require an annual application of nearly 80 million tons of liming materials. This level will not be achieved without extraordinary educational or crop-production campaigns. At the rate of increase over the past few years, something less than half of the needed increase in annual lime use will be achieved by 1975.

The consumption of trace-element materials has assumed sizable proportions in recent years. Use of trace elements in fertilizers will continue to increase steadily. Annual applications are required in deficiency areas, and new areas of deficiency are continually being discovered. Increased use of fertilizers in general, like all other good production practices, will reveal the existence of borderline

deficiency areas. There is no era of universal trace-element deficiencies in sight, but trace-element problems will receive increasing attention, particularly in the South. It seems likely that there will be a three- or fourfold increase in use of the trace elements during the next two or three decades.

Sulfur is currently in short supply, and much of the future increase in phosphate-fertilizer tonnage will probably be achieved without a corresponding increase in sulfur consumption. Use of phosphate fertilizers that do not carry sulfur will show up areas of sulfur deficiency, and may necessitate direct applications of elemental sulfur, gypsum or other sulfur-carrying materials.

## IV. RESOURCES OF FERTILIZER RAW MATERIALS

In common with the rest of the world, the United States has an inexhaustible resource of nitrogen in the atmosphere. We also have huge resources of carbonaceous materials, with the aid of which the atmospheric nitrogen can be converted into products useful to both industry and agriculture.

The United States produces nearly half of the world output of phosphate rock, and our reserve of this material is exceeded only by that of French Morocco. During the past 25 years great progress has been made in the mechanization of the mines and in the improvement of mining and beneficiation techniques. Important measures have been adopted for the conservation and utilization of low-grade phosphate rock and for the recovery of valuable coproducts.

By virtue of the development of the New Mexico deposits, the United States has been self-sufficient in supplies of potash since 1940. The proved gross reserve of potash in brines and deposits of highly soluble minerals that can be mined economically under present conditions is estimated to be approximately 250 million short tons of $K_2O$. Other occurrences of soluble potash, apparently of great potential importance, are known.

Very large resources of sulfur (chiefly in nonelemental forms), calcium, and magnesium materials are widely distributed over the country.

California has the world's largest reserve of boron minerals. Among the other trace-nutrient elements, the United States produces large tonnages of copper and zinc, but our position in manganese is less satisfactory.

Although we have very large resources of fertilizer raw materials, which are substantially supplying the Nation's requirements of plant nutrients and are providing quantities for export, we cannot

afford to be complacent. We must continue to seek better methods of utilizing our known resources, as well as to explore for additional resources.

## NITROGEN MATERIALS

In the descending order of their present importance, the United States resources of commercial-fertilizer nitrogen are in the atmosphere, deposits of coal and other mineral fuels, and natural organic materials. The Nation has no commercial deposits of natural nitrates.

Natural organic materials, such as plant residues, fish products, and animal tankages, formerly furnished the greater portion of the domestic supply of nitrogen for commercial fertilizers. For several reasons discussed elsewhere in this report, such materials are now of only minor significance, and it appears that they will not again play an important part in the country's fertilizer industry.

## NITROGEN FROM THE ATMOSPHERE

For about 30 years the Nation's consumption of nitrogen for industrial and technical purposes has been supplied mostly by ammonia produced synthetically from atmospheric nitrogen. During the same time, synthetic ammonia has become an increasingly important factor in the fertilizer industry. It now furnishes more than 65 percent of our annual consumption of commercial-fertilizer nitrogen, and the proportion will undoubtedly increase.

Since atmospheric nitrogen is readily available in inexhaustible quantity, the problem of its utilization is primarily one of the facilities for its conversion into useful products and of supplies of the raw materials necessary for this conversion.

Economical manufacture of synthetic ammonia depends on adequate supplies of low-cost hydrogen. The hydrogen may be obtained by electrolysis of water or by reactions involving a wide variety of carbonaceous materials such as coal, coke, natural gas, coke-oven gas, oil-refinery gas, petroleum, and wood. Relatively small quantities of ammonia are manufactured with byproduct hydrogen from the caustic soda - chlorine industry. Attention is being given to the utilization for ammonia manufacture of byproduct hydrogen from certain organic chemical industries.

At present, natural gas is the cheapest source of hydrogen for large-scale ammonia synthesis in the United States. This situation may not prevail, however, over a long period of time. The rapidly growing demand for natural gas for a multitude of purposes, coupled with the ultimately decreasing supplies, will eventually make its

cost prohibitive for ammonia synthesis. This might happen before 1975. Over the long range, major reliance must be placed on coal and its derivatives for the hydrogen requirement of ammonia synthesis.

## NITROGEN FROM MINERAL FUELS

Nitrogen recovered as a byproduct of the coking of coal has been an important factor in the domestic fertilizer industry for some 40 years. During most of the period 1910 to 1943 a higher proportion of the domestic consumption of fertilizer nitrogen was supplied as a byproduct of the coke industry than by any other single source. Subsequently, coke-oven nitrogen has yielded first place to nitrogen fixed synthetically from the atmosphere. Since the output of coke-oven nitrogen depends chiefly on the production of pig iron, it can be expected to supply a diminishing portion of the rapidly expanding consumption of fertilizer nitrogen, but it will continue to be produced and used in increasing quantities.

The United States has huge resources of coking coal, which averages about 1.5 percent of nitrogen. Approximately 13 percent of the nitrogen can be recovered as ammonia and ammonium sulfate in byproduct coke plants.

The Nation has enormous reserves of other nitrogen-bearing mineral fuels—notably lignite in the Dakotas and other States and oil shale in the West—which are important potential sources of byproduct nitrogen.

Lignite contains 0.7 to 1.5 percent of nitrogen. Some 3 to 5 pounds of nitrogen as ammonia can be recovered from a ton of lignite by carbonizing under suitable conditions. The North Dakota deposits alone are estimated to contain several hundred billions of tons of lignite. Methods for the utilization of lignite by carbonization and other means are well developed, but the domestic deposits do not generally lend themselves to economical exploitation at present. It is significant, however, that plans have been announced for the construction of a large plant for carbonizing lignite in Texas.

Deposits of oil shale, aggregating many billions of tons, are widely distributed in the West, notably in Colorado, Utah, and Wyoming. The shale contains about 0.5 percent of nitrogen, of which approximately 3 pounds can be recovered as ammonia for each ton of shale processed for production of liquid fuels. The economics of processing shale for oil are sufficiently promising that commercial production is expected in the very near future. Within the next few years oil shale may well be an important factor in the Nation's liquid fuel industry, in which event it could make a significant contribution to the supply of fertilizer

nitrogen. It should be pointed out, however, that the economics of recovery of the nitrogen may not be generally favorable, so that the tendency may be to waste the ammonia rather than to attempt its utilization.

## PHOSPHATE MATERIALS

The principal phosphate raw materials for commercial fertilizer in the United States are phosphate rock, bone, and iron ore. Among the various materials, phosphate rock supplied more than 98 percent of the 1,884,000 short tons of available $P_2O_5$ used as commercial fertilizer in the United States and Territories in the calendar year 1949. Bone formerly held a prominent place in the domestic fertilizer industry but is now of only minor importance, because of the relatively small supply and its greater value as a low-fluorine phosphorus supplement in live-stock feeds. Phosphatic slags, obtained as byproducts of the manufacture of steel from high-phosphorus iron ores, supply large quantities of fertilizer phosphorus in some parts of the world, notably Europe, but they have been of small importance in the United States.

As used in this report, the term "phosphate rock" includes the mineral, apatite, as well as a variety of high-phosphorus rocks, and it comprises chiefly materials consisting essentially of fluorine-bearing calcium phosphates.

There are several types of phosphate-rock deposits, the most important of which are the sedimentary varieties precipitated from sea water in extensive beds, such as those in North Africa, western United States, and some of the Florida deposits. Residual deposits accumulate on or near the surface when phosphatic limestones undergo weathering, for example, some of the deposits in Florida, Tennessee, and the Pacific islands. Other types include vein deposits of apatite (Ontario, Canada and the Kola Peninsula, U. S. S. R.) and those resulting from deposition of bird excrement (some of the Pacific island deposits).

Mining of phosphate rock in the eastern United States is presently by the open-pit method, usually with beneficiation by such means as washing, screening, settling, and flotation. Both open-pit and underground mining methods are used in the western phosphate field. The western rock occurs in hard, consolidated masses and is less amendable to beneficiation than the eastern material; in general, therefore, selective mining is done, and subsequent concentration of the rock by ore-dressing methods is little practiced.

The grades of phosphate rock are expressed in terms of either tri-calcium phosphate—$Ca_3(PO_4)_2$, commonly designated in the trade

as "bone phosphate of lime" (B. P. L.)—or phosphoric oxide ($P_2O_5$). The commercial rock generally contains 60 to 77 percent of B. P. L. (27 to 35 percent of $P_2O_5$), although material from some of the Pacific islands often averages 80 to 88 percent of B. P. L. For some purposes, such as direct application to the soil and manufacture of elemental phosphorus, lower grades of rock can often be used economically.

Coproducts obtainable in connection with the mining, beneficiation, and processing of domestic phosphate rock include fluorine compounds, ferrophosphorus, lightweight aggregate, vanadium from some of the western rocks, and monazite, ilmenite, rutile, and zircon from the Florida land-pebble deposits. Some types of phosphate rock contain small percentages of uranium and promise to become important sources of this element.

The bulk of the phosphate rock produced throughout the world is made into fertilizers. A considerable and increasing tonnage is used, however, in the manufacture of a wide variety of chemicals for military, technical, and industrial purposes, especially in the United States.

Phosphate fertilizer manufacture is usually by processes involving treatment of the rock with sulfuric acid to produce ammonium phosphates, triple superphosphate, or chiefly normal superphosphate. Other processes include those involving treatment of the rock with nitric acid, heating with alkali salts or magnesium silicates, thermal defluorination, and smelting with silica and coke in electric or blast furnaces to obtain elemental phosphorus as the primary product. Manufacture of phosphate chemicals is accomplished either with the aid of sulfuric acid or by means of the smelting process.

## WORLD PRODUCTION AND RESOURCES

The world production of phosphate rock increased eightfold from 2.7 million long tons in 1900 to about 22.5 million tons in 1950. Of the production in the latter year, 49 percent was from deposits in the United States, 29 percent from North Africa (Algeria, Egypt, Morocco, and Tunisia), and the remainder from some 30 other countries but chiefly the U.S.S.R., Nauru and Ocean Island, French Oceania, and Christmas Island.

The world reserve of phosphate rock is estimated to total at least 46 billion long tons. A high proportion of the reserve is believed to be in deposits of such nature and quality as to permit its economical mining and utilization under the conditions presently prevailing in the respective countries. About 85 percent of the reserve is in the free-world countries.

Table 8. - Statistics of phosphate rock in the United States, 1900-1950

| Calendar year | Marketed production 1/ | Imports | Exports | Apparent consumption 2/ | Average value per ton 3/ |
|---|---|---|---|---|---|
| | 1,000 long tons | 1,000 long tons | 1,000 long tons | 1,000 long tons | Dollars |
| 1900 | 1,491 | 137 | 620 | 1,008 | 3.59 |
| 1901 | 1,484 | 176 | 730 | 930 | 3.58 |
| 1902 | 1,490 | 137 | 802 | 826 | 3.15 |
| 1903 | 1,582 | 133 | 785 | 929 | 3.36 |
| 1904 | 1,874 | 130 | 842 | 1,162 | 3.51 |
| 1905 | 1,947 | 56 | 935 | 1,069 | 3.47 |
| 1906 | 2,081 | 23 | 904 | 1,200 | 4.12 |
| 1907 | 2,265 | 26 | 1,018 | 1,273 | 4.71 |
| 1908 | 2,386 | 27 | 1,188 | 1,224 | 4.78 |
| 1909 | 2,338 | 12 | 1,021 | 1,330 | 4.62 |
| 1910 | 2,655 | 22 | 1,083 | 1,594 | 4.11 |
| 1911 | 3,053 | 16 | 1,247 | 1,823 | 3.90 |
| 1912 | 2,973 | 29 | 1,207 | 1,796 | 3.93 |
| 1913 | 3,111 | 17 | 1,367 | 1,762 | 3.79 |
| 1914 | 2,734 | 15 | 964 | 1,785 | 3.51 |
| 1915 | 1,836 | 5 | 253 | 1,588 | 2.95 |
| 1916 | 1,982 | 5 | 244 | 1,743 | 2.97 |
| 1917 | 2,584 | (4)/ | 166 | 2,418 | 3.01 |
| 1918 | 2,491 | 0 | 143 | 2,347 | 3.30 |
| 1919 | 2,272 | (4)/ | 379 | 1,893 | 5.10 |
| 1920 | 4,104 | (4)/ | 1,070 | 3,034 | 6.11 |
| 1921 | 2,064 | 4 | 733 | 1,334 | 5.94 |
| 1922 | 2,418 | 6 | 719 | 1,704 | 4.34 |
| 1923 | 3,007 | 7 | 828 | 2,186 | 3.85 |
| 1924 | 2,868 | 16 | 819 | 2,065 | 3.57 |
| 1925 | 3,482 | 3 | 870 | 2,614 | 3.32 |
| 1926 | 3,210 | 17 | 749 | 2,478 | 3.39 |
| 1927 | 3,171 | 28 | 918 | 2,281 | 3.55 |
| 1928 | 3,501 | 46 | 899 | 2,648 | 3.55 |
| 1929 | 3,761 | 45 | 1,143 | 2,663 | 3.50 |
| 1930 | 3,926 | 33 | 1,226 | 2,733 | 3.56 |
| 1931 | 2,535 | 13 | 951 | 1,597 | 3.66 |
| 1932 | 1,707 | 13 | 613 | 1,107 | 3.36 |
| 1933 | 2,490 | 8 | 829 | 1,669 | 3.16 |
| 1934 | 2,835 | 0 | 993 | 1,841 | 3.54 |
| 1935 | 3,042 | 4 | 1,104 | 1,942 | 3.60 |
| 1936 | 3,352 | 3 | 1,209 | 2,146 | 3.40 |
| 1937 | 3,956 | 13 | 1,053 | 2,917 | 3.28 |
| 1938 | 3,739 | 7 | 1,141 | 2,605 | 3.46 |
| 1939 | 3,757 | 4 | 949 | 2,812 | 3.27 |
| 1940 | 4,003 | 3 | 751 | 3,254 | 3.08 |
| 1941 | 4,690 | 4 | 1,020 | 3,674 | 3.33 |
| 1942 | 4,644 | 4 | 529 | 4,119 | 3.57 |
| 1943 | 5,126 | 47 | 358 | 4,815 | 3.70 |
| 1944 | 5,377 | 123 | 439 | 5,061 | 3.88 |
| 1945 | 5,807 | 142 | 491 | 5,458 | 4.12 |
| 1946 | 6,861 | 60 | 5/ 633 | 6,287 | 4.52 |
| 1947 | 9,027 | 43 | 6/ 1,643 | 7,428 | 5.17 |
| 1948 | 8,669 | 48 | 7/ 1,141 | 7,576 | 5.83 |
| 1949 | 8,987 | 65 | 7/ 1,258 | 7,794 | 5.72 |
| 1950 | 10,254 | 87 | 1,832 | 8,509 | 5.76 |

1/ Sold or used by producers.
2/ Marketed production plus imports minus exports. In some years the figures do not coincide with those derived directly from the data of columns 2, 3, and 4, because of the rounding of the respective figures to the nearest 1,000 tons.
3/ Value at mines.
4/ Less than 500 tons.
5/ Does not include exports under Army Civilian Supply Program.
6/ Includes 890,000 tons exported to Japan and Korea under Army Civilian Supply Program.
7/ Includes exports under Army Civilian Supply Program.

U. S. Bureau of Mines and U. S. Bureau of the Census.

Of the total reserve of phosphate rock, French North Africa (Algeria, Morocco, and Tunisia) has 51 percent, the United States 29 percent, and the Soviet Union 16 percent. The remainder is distributed among many other countries, chiefly Brazil, Egypt, and the islands of the Pacific and Indian Oceans.

It appears certain that the reserve of economically minable phosphate rock will be greatly augmented by future developments and discoveries. A number of little-studied occurrences of phosphate that may prove of importance have been found in recent years, for example, in Indo-China, Uganda, Venezuela, and Brazil. Furthermore, relatively little search has yet been made for phosphate in large areas of the world, notably South America, Asia except parts of the Soviet Union, and Africa other than the northern coastal areas. Also, the known deposits contain enormous quantities of phosphate that for various reasons is not economically utilizable at present. Developments in mining, beneficiation, and processing, together with other factors, will undoubtedly add much of this phosphate to the category of usable material.

## DOMESTIC PICTURE

Since 1867, the first year of commercial production from the South Carolina deposits, the United States has not only been virtually independent of foreign sources of phosphate rock but has supplied large quantities of this material to the world markets. Over the years the Nation's resources of phosphate have been greatly augmented by the successive discovery and development of the large deposits in Florida, Tennessee, and Idaho, Montana, Utah, and Wyoming.

### Production, Consumption, and Trade

In the period 1900 to 1950 the annual marketed production of phosphate rock in the United States increased from approximately 1.5 million to 10.3 million long tons (table 8). During the same time the apparent domestic consumption of this material increased from about 1 million to 8.5 million tons. The exports in 1950 (some 1.8 million tons) were triple those in 1900. The imports of phosphate rock—except for a few years, considerably less than 100,000 long tons annually—have generally consisted of special materials or isolated shipments obtained under temporarily favorable conditions.

The domestic production of phosphate rock in 1900 came almost entirely from the deposits in Florida (47 percent), Tennessee (31 percent), and South Carolina (22 percent). Subsequently, mining of the South Carolina deposits was ceased, and operations in the

Idaho-Montana-Utah-Wyoming field were started. Owing, however, to more favorable mining conditions and costs, proximity to major domestic markets, and accessibility for export shipments, an increasingly large portion of the total output has come from the Florida deposits. Thus, in 1950 Florida supplied 79 percent of the Nation's marketed production of phosphate rock, as compared with 14 percent from Tennessee and 7 percent from the Western States.

The output of phosphate rock in 1950 was produced by 29 companies. Of these companies, 12 mined phosphate in Florida, 7 in Tennessee, 2 in both Florida and Tennessee, and 8 in the Western States.

With a few exceptions, the greater portion of the annual domestic production of phosphate rock has always been consumed within the country. The proportion has increased markedly in recent years; it was 82 percent in 1950. The exports have been chiefly to Canada, western Europe, and Japan. For the near future at least, the distribution of exports is likely to follow generally the present pattern, with the prospect of a rather substantial increase in the currently small shipments to Latin American countries.

As in the rest of the world, the domestic consumption of phosphate rock is chiefly for fertilizer purposes—about 77 percent in 1949. This will certainly continue to be by far the dominant use. Another agricultural outlet for phosphate rock, relatively small at present, is in the manufacture of low-fluorine products for use as phosphorus supplements in the feeding of livestock. Since the demand for feed-grade phosphate has become so great that it can no longer be met by the traditional material, bonemeal, utilization of phosphate rock for this purpose can be expected to expand considerably. Certain organic phosphorus compounds are very potent insecticides.

There are no substitutes for phosphates in the fields of plant and animal nutrition.

In recent years, progressively larger tonnages of phosphate rock have been consumed in the manufacture of chemicals for military, technical, and industrial purposes, and this trend is continuing. Some of the many uses for these chemicals are in water conditioning, detergents, food processing and products, fireproofing, plastics, petroleum production and processing, pharmaceuticals, metal cleaning and protection, insecticides, phosphorus bombs and shells, and manufacture of matches, alloys, ceramics, glass, and textiles.

The average value of phosphate rock during most years of the period 1900 to 1950 was about $3.50 per long ton at the mines (table 8). The values ranged from approximately $4 to as much as $6 in some years, namely, in 1906 to 1910, 1919 to 1922, and since 1944.

There was no tariff on phosphate rock and phosphate fertilizers in 1900 to 1950. The duty on elemental phosphorus is 8 cents per pound.

Compared with an increase of 2 percent per annum in the gross national product, the increase in chemicals as a whole has been 5 percent. The increase in phosphate chemicals, on the other hand, has been and is likely to continue to be greater than 5 percent.

Commercial utilization of byproduct phosphates in the United States is confined to a relatively few materials. The bone byproducts include meals and tankages for fertilizers and for animal feeding, and dicalcium phosphate is obtained as a byproduct of the manufacture of gelatin and glue from bones. One company supplies for fertilizer use a basic slag (8 percent or more of $P_2O_5$) from the smelting of phosphatic iron ore in Alabama. Fertilizer-grade phosphates are obtained as byproducts of the processing of phosphate rock for manufacture of certain chemicals. Re-use, principally as fertilizer, is made of spent phosphate materials from some industrial and technical processes.

## Domestic Resources

The Nation's phosphate resources are mainly in the Western States of Idaho, Montana, Utah, and Wyoming, and in Florida and Tennessee. Minor deposits exist in Arkansas, Kentucky, South Carolina, and Virginia, and occurrences of phosphate are known in a number of other States.

The present minable or economic reserve of phosphate rock totals about 4 billion long tons, of which approximately 1.5 billion are in the Western States, 0.1 billion in Tennessee, and most of the remainder in Florida. The reserve of lower grade phosphate and of phosphate so situated that it cannot be mined economically—if at all—under present conditions is enormous. Our resources of fairly high-grade phosphate, not minable under present conditions, total at least 9 billion long tons, of which 2.5 billion are in Florida and the remainder is mostly in the western field. Resources of low-grade material--containing as little as 5 percent of $P_2O_5$—probably amount to scores or even hundreds of billions of tons.

Although the domestic economic reserve of phosphate rock is very large, it is by no means a simple matter for a new company entering the field to find suitable deposits. Many of the best and most favorably situated deposits, particularly in Florida and Tennessee, are owned by the large operating companies. Moreover, the investment required for efficient operation is often so great that small companies with limited capital cannot compete.

No estimate is available of the reserve of phosphorus in iron ores, that might be recoverable as basic slag in the manufacture of steel.

## Technological Advances and Their Significance

In the past 25 years two notable technological advances have been made which have not only prolonged the domestic phosphate deposits but also have brought into the economic picture low-grade phosphates that were formerly considered uneconomical to exploit.

One of these developments is the separation of finely divided phosphate particles from silica grains by flotation processes that make possible the recovery of approximately twice as much phosphate from the pebble deposits of Florida and have brought many formerly submarginal deposits into the economic reserve.

The other development is the manufacture of elemental phosphorus directly from lower-grade phosphates by the electric- and blast-furnace processes. These processes require the presence of substantial quantities of silica in order to smelt the phosphate charge, and it is often more economical to use relatively low-grade siliceous phosphates—containing 23 to 25 percent of $P_2O_5$—than to add silica to high-grade rock. Thus, certain phosphate deposits unsuited to beneficiation for production of the grades of rock required for treatment by the conventional sulfuric acid process have been raised to the level of economic reserves.

There will undoubtedly be further improvements and developments in the methods and techniques of the mining, beneficiation, and processing of mineral phosphates which will bring additional large quantities of these materials into the economic reserves.

## Role of U. S. Government

Most of the phosphate deposits in the Western States and some of those in Florida are in Federal land and are specifically withheld from the staking of claims. The Department of the Interior, through the Bureau of Land Management, encourages private development of the Government-owned deposits on a lease basis with payment of royalties. The Geological Survey prospects Federal land to classify it as mineral or nonmineral; studies the geology of the phosphate deposits; and determines the quality and quantity of the ore. The Bureau of Mines performs research on methods of mining and beneficiating phosphate rock. The Department of the Interior has made studies of production costs, transportation economics, and market potentials of western phosphate rock and products manufactured therefrom.

The Department of Agriculture conducts studies and researches on phosphate and other fertilizers, including: methods of processing the raw materials and the technology of the products and their utilization; chemical and agronomic evaluation of fertilizers, and the economics of their use in crop production; fertilizer requirements of crops and cropping systems, and the influence of fertilizers on the composition, quality, and nutritional value of crops; and compilation and analysis of statistical information on fertilizer production, consumption, and use. The Department of Agriculture renders educational, technical, and financial assistance to farmers in the use of fertilizers for soil conservation and improvement; aids farmer cooperatives in establishing and financing facilities for fertilizer production and distribution; and cooperates with other Federal agencies and the fertilizer industry in securing production of the Nation's requirements of fertilizers.

The Tennessee Valley Authority mines and beneficiates phosphate rock and conducts research on problems relating thereto; engages in large-scale production of elemental phosphorus and certain phosphate and nitrogen fertilizers; conducts research and development of improved fertilizer processes; supports studies of the agronomic evaluation of fertilizer materials produced by the Authority, and of the efficiency and utilization of such materials in improved farming systems; and fosters farm-test demonstrations of fertilizers in the Tennessee Valley area.

The Atomic Energy Commission is vitally concerned with the recovery of uranium in the processing of phosphate rock for production of fertilizers and chemicals.

The United States Government does not stockpile phosphate rock. There are ample reserves within the country to meet any contingency. The European democracies rely largely on North Africa's ample supplies. It is to the interest of the Government that domestic phosphate be available for export to the free-world countries, as may be needed.

## Problems of Materials and Their Utilization

The major long-range problems of phosphate materials include (1) better delineation of the quantity and quality of phosphate rock in the deposits that are economically usable under present conditions, (2) more efficient utilization of the low-grade rock in presently worked deposits, (3) development of methods for economical utilization of submarginal and low-grade deposits, and (4) availability of sulfuric acid for converting phosphate rock into fertilizers and the use of alternative processes.

The western deposits contain about 60 percent of the total United States reserve (some 13 billion long tons) of phosphate rock, but only about 40 percent of the economic reserve (approximately 4 billion tons). Owing to the long distance of the western deposits from the major markets for phosphate fertilizers and chemicals, the rock must generally be processed at or near the mines into highly concentrated products. The rapidly progressing developments in the production and use of the western rock emphasize the need for continuing search for deposits capable of economic utilization, not only with respect to the characteristics of the deposits and the quantity and quality of the ore but also as regards supplies of electric power, coal, sulfuric acid, and other processing requirements.

Despite the great advances made in recent years in the recovery of values from phosphate deposits, there is still room for much improvement. For example, the recovery of very finely divided phosphate in the mining and beneficiation of Florida rock is an important problem. In the western deposits the economically usable rock is commonly associated with much larger quantities of lower grade material that is not amenable to beneficiation or utilization by present methods. Solution of these problems would be a major contribution to the conservation of the Nation's phosphate resources.

For the most part, the deposits of Tennessee blue-rock phosphate are not economically usable at present. Associated with both the blue-rock and brown-rock deposits are extensive occurrences of phosphatic limestones. Because of the relatively small economic reserve of Tennessee phosphate (only about 100 million tons), studies should be directed toward the development of methods and techniques for the utilization of the blue rock and the phosphatic limestone.

Little is known of the phosphatic marls which are said to occur in extensive deposits in certain parts of Florida, or of the bedrock—reported to be highly phosphatic in some places—underlying the Florida pebble and hard-rock deposits.

Studies should be continued of the long-range position of supplies of sulfuric acid compared with that of nitric and other acids which may be used for the processing of phosphate rock. Full utilization of the sulfur-bearing gases from nonferrous-metal smelters is a significant phase of this problem, especially with respect to manufacture of fertilizers from western rock. Provision of adequate supplies of low-cost electric power and intensified study of local coal resources as regards their adaptability to the processing of phosphate rock are other important segments of the western phosphate problem.

Continuing studies should be made of the technology and economics of processes for treating phosphate rock, with special reference to those that do not involve the use of sulfuric acid—production of elemental phosphorus, using electricity or, particularly, coal as the heat source; thermal defluorination; heating with alkalies such as soda ash, or magnesium silicates such as olivine or serpentine; and treatment with nitric acid.

## POTASH MATERIALS

The term "potash" is loosely applied to potassium compounds in general. Most specifically, it refers to the oxide, $K_2O$. The potassium content of materials is commonly expressed in terms of equivalent $K_2O$.

The deposits of potash that are presently of commercial importance were formed, in most instances, by the evaporation of sea water in land-locked basins. Subterranean deposits of this kind are the source of most of the commercial potash. Some potash is recovered from salt lakes, such as Searles Lake in California and the Dead Sea, and from subterranean brines. Other sources, of relatively little commercial significance at present, are vegetable materials, byproducts of certain industrial operations, and a number of water-insoluble minerals and rocks.

The potash mineral of greatest commercial importance in the United States is sylvite—potassium chloride, KCL (63.1 percent of $K_2O$). Langbeinite—potassium magnesium sulfate, $K_2SO_4 \cdot 2MgSO_4$ (22.6 percent of $K_2O$)—is a minor source. A potential source of potash, of which the United States has a large reserve, is the mineral polyhalite--a hydrous sulfate of potassium, magnesium, and calcium, $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$ (15.5 percent of $K_2O$).

The New Mexico potash beds are mined by underground methods at a depth of about 1,000 feet. The crude salt is concentrated either by flotation or by fractional crystallization. Potash is recovered from the Searles Lake and the Salduro Marsh, Utah, brines by evaporation and fractional crystallization. Concentration of the crude salts into finished products is effected at or very near the deposits.

Potassium chloride containing 60 to 62 percent of $K_2O$ is the principal potash salt produced in the United States. Other fertilizer types and grades chiefly comprise lower quality potassium chloride (48 to 50 percent of $K_2O$), potassium sulfate (50 to 52 percent of $K_2O$), sulfate of potash-magnesia (21 to 22 percent of $K_2O$), and manure salts (24 to 26 percent of $K_2O$).

Sodium sulfate, sodium carbonate, boron compounds, and lithium salts are obtained as coproducts of the recovery of potash from the Searles Lake brine.

By far the greater portion of the world production of potash is used as fertilizer. A relatively small quantity is used for a wide variety of chemical, technical, and industrial purposes.

## WORLD PRODUCTION AND RESOURCES

The world production of potash in the year ended June 30, 1951, is estimated at approximately 4.7 million short tons of equivalent $K_2O$, exclusive of the U.S.S.R. This was about 1.5 times the production in 1938. Of the estimated production in 1950-51, 49 percent was in Germany (21 percent in the Federal Republic), 26 percent in the United States, and 21 percent in France. The remainder was chiefly in Spain.

Satisfactory data on the world reserve of potash are not available. This is because of the wide variations in the published estimates and the lack of information as to the bases on which much of the data were calculated. It is conservatively estimated, however, that the total reserve of potassium salts in highly soluble minerals and natural brines exceeds 5.5 billion tons of $K_2O$—mostly, if not entirely, in the form of materials capable of being mined and processed economically under the conditions presently prevailing in the individual countries. The reserve of marginal and submarginal potash in highly soluble minerals is certainly very much larger than 5.5 billion tons.

The principal reserves are located in only a few countries, namely, Germany, the Soviet Union, Israel-Jordan, France, Spain, and the United States. In addition, large but as yet only partially evaluated deposits of highly soluble potash minerals have been found in Canada and England. Other deposits, for which reserve data are lacking, include those in Chile and certain African countries.

The world has huge resources of potash in forms that, in general, are not amenable to economical mining and processing under present conditions. These forms include slowly soluble minerals—such as polyhalite—and insoluble minerals and rocks such as alunite, greensand, leucite, and certain shales and feldspars. The ocean averages about 0.05 percent of $K_2O$ and is a potential inexhaustible source of potassium compounds. Potash accumulates in seaweeds, from which it may be recovered in various ways.

Table 9. - Statistics of potash in the United States, 1915- 1950

| Calendar year | Marketed production1/ | Imports2/ | Exports | Apparent consumption3/ | Average value per ton4/ |
|---|---|---|---|---|---|
| | 1,000 short tons of $K_2O$ equivalent | 1,000 short tons of $K_2O$ equivalent | 1,000 short tons of $K_2O$ equivalent | 1,000 short tons of $K_2O$ equivalent | Dollars |
| 1915 | 1 | 49 | (5)/ | 6/ 50 | 313.76 |
| 1916 | 10 | 8 | (5)/ | 6/ 18 | 436.49 |
| 1917 | 33 | 8 | (5)/ | 6/ 41 | 429.21 |
| 1918 | 39 | 8 | (5)/ | 6/ 47 | 410.57 |
| 1919 | 46 | 40 | (5)/ | 6/ 85 | 246.49 |
| 1920 | 41 | 225 | (5)/ | 6/246 | 180.07 |
| 1921 | 4 | 79 | (5)/ | 6/ 83 | 101.60 |
| 1922 | 11 | 201 | 3 | 210 | 40.97 |
| 1923 | 19 | 210 | 2 | 228 | 40.70 |
| 1924 | 22 | 200 | 1 | 221 | 38.51 |
| 1925 | 26 | 258 | 1 | 283 | 46.66 |
| 1926 | 25 | 266 | (5)/ | 6/291 | 43.22 |
| 1927 | 50 | 244 | (5)/ | 6/294 | 49.46 |
| 1928 | 60 | 330 | (5)/ | 6/391 | 50.18 |
| 1929 | 58 | 325 | 7/ 9 | 7/374 | 51.94 |
| 1930 | 57 | 342 | 7/ 9 | 7/390 | 52.75 |
| 1931 | 64 | 215 | 7/17 | 7/262 | 48.41 |
| 1932 | 56 | 114 | 7/ 2 | 7/168 | 37.80 |
| 1933 | 139 | 172 | 7/18 | 7/293 | 38.09 |
| 1934 | 114 | 172 | 7/11 | 7/275 | 24.65 |
| 1935 | 225 | 242 | 7/43 | 7/424 | 22.22 |
| 1936 | 223 | 212 | 7/58 | 7/377 | 31.28 |
| 1937 | 267 | 351 | 62 | 556 | 33.79 |
| 1938 | 286 | 194 | 52 | 428 | 34.03 |
| 1939 | 366 | 100 | 84 | 383 | 32.84 |
| 1940 | 393 | 119 | 63 | 449 | 31.96 |
| 1941 | 531 | 16 | 57 | 490 | 32.69 |
| 1942 | 681 | 4 | 49 | 636 | 33.73 |
| 1943 | 732 | 17 | 70 | 679 | 35.76 |
| 1944 | 818 | 5 | 69 | 754 | 36.05 |
| 1945 | 870 | 6 | 68 | 809 | 34.83 |
| 1946 | 928 | 4 | 66 | 867 | 34.66 |
| 1947 | 1,053 | 26 | 68 | 1,011 | 32.96 |
| 1948 | 1,143 | 27 | 70 | 1,101 | 31.49 |
| 1949 | 1,121 | 19 | 70 | 1.070 | 31.33 |
| 1950 | 1,275 | 199 | 65 | 1,410 | 31.12 |

1/ Sold or used by producers.
2/ During the period 1905 to 1914 the imports ranged from 129,000 tons in 1905 to 280,000 tons in 1910.
3/ Marketed production plus imports minus exports. In some years the figures do not coincide with those derived directly from the data of columns 2, 3, and 4, because of the rounding of the respective figures to the nearest 1,000 tons and for other reasons as indicated.
4/ Average value of domestic production per ton of $K_2O$ equivalent at plant.
5/ Figure not available in terms of $K_2O$; tonnage was small.
6/ Includes the small tonnage of exports.
7/ Approximate.

U. S. Bureau of Mines

## DOMESTIC PICTURE

In 1900 the domestic output of potash salts totaled 2,000 short tons of $K_2O$ equivalent, all from wood ashes. The production continued to be on a very small scale until World War I. With the cessation of imports from Germany early in 1915, strenuous effort was made to develop a substantial potash industry in the United States.

At the close of World War I, 128 plants were producing potash salts from a variety of sources but chiefly from the brines of Nebraska Lakes and of Searles Lake. Even so, the total output was far below the quantity needed for domestic agriculture and industry. High production costs and the resumption of importations from Germany soon forced most of the domestic producers to close down. A few plants, notably the one at Searles Lake, were able to continue in operation, however, and to increase gradually the total domestic output.

The initiation in 1931 of production of potash from the recently discovered deposits of soluble minerals in New Mexico marked the beginning of a new era in the domestic potash industry, an era which by 1941 had witnessed the development of the industry on a scale capable of supplying the Nation's entire requirement for potash.

### Production, Consumption, and Trade

Statistics of potash in the United States for the period 1915 to 1950 are given in table 9. The annual marketed production of domestic potash first reached 100,000 tons of $K_2O$ equivalent in 1933 (47 percent of the apparent domestic consumption in that year), 500,000 tons in 1941, and 1,000,000 tons in 1947. The marketed production in 1950 was 1,275,000 tons, or nearly 20 times the output in 1931--the first year of production from the New Mexico deposits. The apparent consumption in 1950 (1,410,000 tons) was 5.4 times that in 1931. The slight recession in the production in 1949 was due to a strike by the New Mexico miners.

The 1950 output of potash salts was produced by seven companies. The three companies operating in New Mexico and the one at Searles Lake, Calif., accounted for over 95 percent of the potash mined in the United States. Three other companies operating, respectively, in Utah (Lake brine), Michigan (subterranean brine), and Maryland (cement-kiln dust) produced the remainder. In addition, two established mining firms are opening properties in New Mexico and are expected to be in operation by 1953. Only one of the nine operations is controlled by a fertilizer-industry company.

Except for 1950 the annual imports of potash have been less than 30,000 tons of $K_2O$ equivalent since 1940. Germany was the

source of the greater portion of the large imports in prior years. Beginning in 1943 the exports of potash have been close to 70,000 tons annually, mostly to Canada.

The domestic use of potash is predominantly for fertilizer. Currently, about 93 percent of the consumption is for such purpose and 7 percent for chemicals. Among the chemical uses of potash salts are the manufacture of soaps, glass, dyes, matches, explosives, fireworks, pharmaceuticals, inks, pigments, baking powders, textiles, and paper and in meat curing, photography, and leather tanning.

There is evidence that sodium can substitute in part for potassium in the nutrition of certain plants. It appears, however, that most, if not all, plants require substantial supplies of potassium for optimum nutrition and development. In many chemical applications soda and potash can be used interchangeably. However, industry already uses soda wherever feasible, because of its much lower cost.

In 1925 to 1950 the annual average value of potash at the producing plants ranged between $22 and $53 per short ton of $K_2O$ equivalent; in more than half the years it was less than $35. The average value in 1950 was $31.12. According to the Bureau of Labor Statistics, in 1949 the price index (1926 = 100) for potash was 81, for fertilizer materials as a group it was 120, for chemicals 119, and for all commodities 155.

Labor costs in the New Mexico potash mines are the highest in the entire mining industry. Modernization of the European potash industry may place the American industry in a less advantageous position.

There is no tariff on potash fertilizer salts.

## Domestic Resources

In discussing domestic potash resources it is customary to take into consideration several different types of raw materials which can be placed in three broad groups, namely (1) highly soluble salts and minerals, (2) slowly soluble minerals, and (3) insoluble minerals and rocks.

The materials in the first group, which contain potassium chiefly in the chloride and sulfate forms, are of the greatest importance. Not only have they supplied fully 98 percent of our potash requirements in the past but they promise to be the main source of potash for many years to come.

The chief material in the second group—consisting of low-analysis, slowly soluble minerals—is polyhalite, of which large quantities occur in the New Mexico and Texas potash deposits. However, polyhalite requires extra processing steps to render it water-soluble and to recover the potash in a form that is sufficiently concentrated to permit its economic shipment over long distances. It appears that under present conditions polyhalite cannot be mined, processed, and marketed in competition with potash from the highly soluble sources.

The third group of potash materials comprises a variety of insoluble minerals and rocks, such as alunite, greensand, leucite, and certain shales and feldspars, which have potash contents ranging from 6 to 10 percent. Although the domestic deposits of these materials—which are widely distributed over the country—contain many millions of tons of potash, the possibility that they will be used to an important extent appears very remote as long as there are adequate reserves of potash in the materials of the other two groups.

The Nation's proved reserve of potash economically recoverable under present conditions is in the New Mexico deposits of highly soluble minerals (sylvite and langbeinite) and in the brines of Searles Lake, Calif., and Salduro Marsh, Utah. As indicated by drill-hole records, the proved gross reserve of potash in brines and deposits of highly soluble minerals that can be mined economically under present conditions amounts to approximately 250 million short tons of $K_2O$. This figure represents the total potash in such brines and deposits. It makes no allowance for the nonrecoverable potash therein, which varies among the deposits and with different mining and refining practices.

The foregoing estimate is based (1) on deposits having a minimum thickness of 4 feet and containing not less than 14 percent and 8 percent of $K_2O$ in the chloride and sulfate ores, respectively, and (2) on natural brines containing an average of 2.5 percent of $K_2O$.

Several thousand tons of potash are recovered annually from well brines in Michigan. No estimate of the potash reserve in these brines is available.

Marginal sources of soluble potash, of which the domestic reserve is certainly large, comprise those deposits that may be exploited after further development of mining and processing technologies or with change in economic conditions. They include thinner strata of salts as well as some beds containing less than the present economic cut-off grades for optimum potash recovery.

Random borings indicate that Utah has deep-lying deposits of soluble potash, possibly of considerable potential importance. Deposits of potash minerals such as sylvite, polyhalite, and carnallite occur in Texas, but little is known of their extent and quality.

Tobacco wastes and other vegetable residues, as well as dried animal-manures, contribute small quantities of fertilizer potash to the domestic supply. Byproduct potash is recovered in a small way at certain cement and molasses-distillery plants, and could be derived also from blast-furnace dust; since the economics of recovering potash from these sources are generally unfavorable, they are expected to remain of very minor importance.

## Technological Advances and Their Significance

The application of flotation as a means of separating highly soluble potash minerals from sodium chloride and other impurities has done much to promote the economic extraction of potash from its natural deposits. A large portion of the output of potassium chloride from the New Mexico deposits is produced with the aid of flotation.

Fractional crystallization, based on the relative solubilities of the various constituents of brines, has contributed salable co-products which pay much of the cost of processing such salines and make possible a lower price for the potash. Potash is recovered in this way from brines in the United States and elsewhere. Fractional crystallization also plays an important role in the recovery of potash from deposits of highly soluble minerals.

The principles of base exchange, double decomposition, and the phase rule have been successfully applied in various ways to the production of potassium sulfate directly from brines and certain highly soluble potash minerals. The domestic output of potassium sulfate is obtained largely by these means.

It can be expected that further developments in potash mining and technology will bring additional tonnages from the marginal sources into the economic picture. For example, solution mining offers the possibility of economical recovery of potash from deep-lying deposits of highly soluble salts.

## Role of U. S. Government

The Nation's reserve of potash in soluble forms is nearly all in Federal land under the jurisdiction of the Department of the Interior. Private development of the Government-owned deposits is

encouraged on a lease basis with payment of royalties. The Geological Survey is concerned with the classification of the land as to its mineral status, and with the geology of the potash deposits and the quality and quantity of the ore. The Bureau of Mines performs research on methods of mining and beneficiating potash ores.

The Department of Agriculture makes studies and investigations of the chemistry, technology, and utilization of potash fertilizers. The work of the Department of Agriculture in this field embraces the various phases outlined for phosphate and other fertilizers in the preceding section on phosphate materials.

The Tennessee Valley Authority conducts researches on the technology of potash fertilizers, principally in relation to products carrying both potash and phosphate.

In postwar Germany it was a policy of the Allies to exclude potash from the materials whose production was restricted. Substantial financial assistance is being given by the Economic Cooperation Administration in the modernization of the French potash mines and refineries.

The United States Government does not stockpile potash in any form. Reserves within the country are ample to meet any possible requirements for a good many years. The other democracies obtain potash largely from Germany, France, and to some extent from Spain. Since the principal non-Soviet European deposits are in Germany or near its border (Alsace, France), the political position of Germany is particularly important as regards potash.

## Problems of Materials and Their Utilization

The Nation's proved reserve of potash in deposits capable of economical mining and processing under present conditions is sufficient to last for many years at the present rate of production. In the last decade, however, the domestic consumption of this highly important plant nutrient has been steadily and markedly upward. If the consumption continues to increase, as is expected, the life of this reserve will be correspondingly shortened. As a means of assuring that the future potash needs of the United States will be met, it is important that a continuing program of exploration be carried on, not only to define more completely the presently known deposits of soluble potash with respect to the extent and quality of the ore but also to determine the potentialities of the other deposits of such potash that are indicated to exist in various parts of the country.

About 85 percent of our present production of potash is in the Carlsbad, N. Mex., area which is serviced by a single railroad. Disruption of service on this railroad could create a serious

situation as regards our potash supply. From the security standpoint, it is desirable that substantial supplies of potash be developed in other parts of the country.

In recent years, the mines and refineries have not been able to supply the demand for potash, but considerable expansion of the facilities is now underway. It is important that the Nation's capacity for producing potash keep well ahead of the increasing demand.

Although the proven reserve of economically recoverable potash in readily soluble forms appears to be sufficient to last for a good many years and it will likely be augmented by further discoveries and developments, consideration should continue to be given to methods for the economic utilization of our vast resources of presently marginal and submarginal materials such as polyhalite, the insoluble potash minerals and rocks, and even sea water.

## CALCIUM AND MAGNESIUM MATERIALS

The Nation's resources of calcium for agricultural use occur in several forms, including calcium carbonate (high-calcium and dolomitic limestones, marl, shells, etc.), calcium sulfate (gypsum and anhydrite), and phosphate rock. Commercial deposits of limestone in the United States and other areas of the world are virtually infinite. Such deposits are widely distributed in practically every State in the Union. Because agricultural limestone is a cheap bulk material, the problem of supplies is chiefly one of quarry location for economical delivery of the product to local farms.

Deposits of marl occur in many of the Eastern and Midwestern States. Deposits of good-quality gypsum and anhydrite are found in a number of States, notably California, Iowa, Kansas, Michigan, Nevada, New York, Ohio, Texas, and Virginia.

Like calcium, magnesium in forms suitable for agricultural use occurs in virtually unlimited quantities in all regions of the world. The most important sources in the United States are high-magnesium limestone and dolomite, supplemented by magnesite, brucite, deposits of soluble minerals (especially langbeinite), well brines, sea water, and silicate minerals.

Deposits of high-magnesium limestone and dolomite are found in many parts of the United States, particularly in the eastern half of the country. Quarries yielding material containing 25 percent or more of magnesium carbonate are located in at least 35 States. Many other quarries produce material of lower magnesium content.

Magnesite and brucite deposits occur in Washington, California, Nevada, and Texas. Magnesium salts are recovered from well brines in Michigan. Recovery of magnesium salts from sea water, an inexhaustible source of such compounds, is practiced on the Pacific, Gulf, and Atlantic Coasts. The langbeinite ore of the New Mexico potash deposits is an important source of fertilizer magnesium in the form of sulfate of potash-magnesia. Large deposits of magnesium silicate minerals, such as olivine and serpentine, occur in North Carolina, California, Washington, and other States, but only very limited use has yet been made of these minerals for agricultural purposes.

## SULFUR MATERIALS

The domestic sulfur resources and their utilization, in relation to the world picture, are discussed in considerable detail in another report of the Commission. Hence, only a brief summary of the situation will be given here.

The sulfur resources of the United States include deposits of native sulfur, metallic sulfides (iron, copper, zinc, and lead), calcium sulfate (anhydrite and gypsum), and alkali sulfates, and natural and oil-refinery gases. Among these resources, native sulfur is presently of the greatest commercial importance, by far. Substantial quantities of elemental sulfur are derived, however, from natural gas, and considerable tonnages of sulfuric acid are made from metallic sulfides and oil-refinery gases. Calcium sulfate in its native state finds agricultural use as a soil amendment in the West and, to a limited extent, as a source of plant-nutrient sulfur in other parts of the country. Plant-nutrient sulfur is also applied to the soil in the form of potassium sulfate fertilizers produced from the potash deposits of New Mexico and California.

The domestic fertilizer industry is a major user of sulfur in the form of sulfuric acid, mostly for the manufacture of superphosphates and ammonium sulfate. About 35 percent of the sulfur consumed in the United States finds its way into fertilizers in the form of sulfuric acid. Substantial additional quantities of sulfur are used in the preparation of agricultural pesticides and for other farm purposes.

Chiefly for economic reasons, more than 90 percent of the available $P_2O_5$ used as fertilizer in the United States—about 2 million short tons in 1950—is manufactured with the aid of sulfuric acid. The current shortage of elemental sulfur and sulfuric acid has focused attention on methods of producing available phosphate fertilizers without the use of sulfuric acid. Such methods, including thermal processes and the treatment of phosphate rock with

nitric acid, have been developed commercially in various parts of the world. They have not yet been applied extensively in the United States, but they can be expected to play an increasingly important role in the domestic industry. It appears, however, that processes involving the use of sulfuric acid will continue to supply the major portion of the Nation's phosphate fertilizer requirements.

The total known reserve of sulfur in the United States, economically usable under present conditions, amounted to at least 98 million long tons of equivalent sulfur as of the middle of 1951. Of this reserve, about half is in the form of native sulfur and most of the remainder is in pyrites deposits. On a comparable basis the total free-world reserve of sulfur is estimated at 358 million long tons, about 83 million tons of which is in the form of native sulfur and 234 million tons in the form of pyrites.

Compared with these reserves, the 1950 production was 6 million long tons of equivalent sulfur in the United States and 11.2 million long tons in the free world. Requirements are expected to be about double these quantities by 1975.

Based on these estimates the reserve of sulfur would become deficient in the United States and possibly in the free world before 1975. Further large discoveries are anticipated, however, and abundant supplies of sulfur are available in lower-grade resources. It is estimated that for at least the next 25 years all requirements for sulfur could be met at an increase in cost of not more than 50 percent. Greatly expanded supplies could come from the mining and processing of pyrites.

Almost unlimited supplies of sulfur also are obtainable, perhaps at further increase in price, from calcium sulfate (anhydrite and gypsum) and other sulfates. Calcium sulfate, which contains 23.5 percent of sulfur on the water-free basis, occurs in vast deposits, not only in the United States but in many foreign countries. Processes for the manufacture of sulfuric acid and cement from calcium sulfate, as well as for the production of ammonium sulfate by treating calcium sulfate with ammonia and carbon dioxide, have been developed and are in commercial operation in several foreign countries. The plant-nutrient requirements for sulfur, which are now supplied largely by normal superphosphate and ammonium sulfate, could be furnished by mineral calcium sulfates in many parts of the country.

## BORON MATERIALS

Reserves of boron in the United States are chiefly in the forms of borax ($Na_2O \cdot 2B_2O_3 \cdot 10H_2O$), kernite ($Na_2O \cdot 2B_2O_3 \cdot 4H_2O$), colemanite ($2CaO \cdot 3B_2O_3 \cdot 5H_2O$), and ulexite ($Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 16H_2O$).

The underground deposits of borates at Boron, Kern County, Calif., probably contain at least 100 million tons of material averaging 40 percent of $B_2O_3$. The reserve in the brines and deposits at Searles Lake, San Bernardino County, California, are estimated at 14 million tons. Additional reserves are known in Nevada and elsewhere in California.

The annual domestic production of boron compounds is equivalent to about 150,000 short tons of $B_2O_3$, mostly as borax from the Kern County deposits and the Searles Lake brines. Usually, about 25 percent of the production is exported. About 10 percent of the domestic consumption is used for plant-nutrient and herbicidal purposes. Boron compounds have many industrial and technical uses.

Although the United States probably has the largest reserve of boron, deposits occur in a number of other countries—Peru, Chile, Bolivia, Argentina, Turkey, Italy, Germany, Tibet, Iran, and the Soviet Union. The Chilean reserve is said to exceed 20 million tons of material containing up to 35 percent of $B_2O_3$. In the rest of the free world, borate production apparently does not exceed 5 percent of the United States output; the most important producers are Argentina, Chile, Turkey and Italy.

The reserve of borates in the United States is such that adequate supplies for agriculture and industry will present no problem by 1975 or for many years thereafter.

## COPPER, MANGANESE, AND ZINC MATERIALS

Since the resources of copper, manganese, and zinc are discussed in detail in other reports of the Commission, only a brief summary of the situation will be given here.

Copper, manganese, and zinc are essential plant-nutrient elements, but they are required in relatively small quantities. Soil deficiencies of these elements are not nearly so common as those of nitrogen, phosphorus, and potassium, and they can often be overcome by applications of as little as 25 pounds of the sulfates per acre. The need for nutrient applications of copper, manganese, and zinc has been recognized in relatively few parts of the country, but the number and size of the deficiency areas are increasing steadily.

The free-world commercial reserves of copper, manganese, and zinc economically available under present conditions are estimated to be adequate to meet the total requirements until at least 1975. The United States will need to supplement its supply of copper and zinc by imports from the more abundant foreign sources, although domestic production will continue to furnish a large share of the

domestic requirements. Most of the new supplies of manganese will continue to come from foreign sources. Use of domestic slags and low-grade resources of manganese can reduce this dependence. Strategic and critical stockpiles of these three elements will need, of course, to be adjusted to compensate for domestic deficiencies.

Low-grade resources of copper, manganese, and zinc are far more abundant than those of the grades presently required for metallurgical purposes. Some of the low-grade resources can be utilized economically for production of fertilizer materials.

## V. MANUFACTURING FACILITIES, METHODS, AND PROCESSING REQUIREMENTS FOR FERTILIZERS

The United States has extensive facilities for the manufacture and processing of fertilizers by modern methods and techniques, all of which are continually undergoing improvement. With a few exceptions, however, the capacity for producing the various plant nutrients, particularly N, $P_2O_5$, and $K_2O$, has not kept pace fully with the demand for such nutrients in recent years. A major problem is that of increasing the capacity to meet the present demand and of insuring continued expansion as the future may warrant.

Although much progress has been made in manufacturing processes and techniques, there is still room for great improvement. Research and development in this field must be expanded and accelerated, if the farmers of the United States are to be supplied with adequate quantities of the most economical and efficient fertilizers in types and forms capable of meeting the increasingly exacting requirements of modern agriculture.

### NITROGEN

The commercial fertilizer nitrogen presently used in the United States is derived from four primary sources. In the increasing order of their importance the sources are (1) natural organic materials, such as oilseed meals, fish products, tankages, sewage products, guanos, dried manures, etc., (2) natural nitrates from Chile, (3) coal, and (4) atmospheric nitrogen. Of the total domestic consumption of commercial fertilizer nitrogen in 1950, these sources supplied roughly 5, 10, 20, and 65 percent, respectively. This is in marked contrast to the situation in 1925 when the same sources supplied, respectively, about 25, 35, 30, and 10 percent of the nitrogen consumption. The data emphasize sharply the Nation's growing dependence on the atmosphere for supplies of fertilizer nitrogen, a dependence which is certain to increase very greatly as time goes on.

With the exception of natural nitrates, of which we have no commercial deposits, the United States produces materials in all of the above-mentioned categories.

## NATURAL ORGANIC NITROGEN

Owing largely to the development of more profitable markets for certain oilseed meals, fish products, and tankages, as animal feeds, the total quantity of natural organic nitrogen available for use as commercial fertilizer has declined to less than half the quantity (some 80,000 tons annually) used in 1910 to 1920. Although the trend is again slightly upward and will probably continue so, as better utilization is made of agricultural, industrial, and municipal wastes, natural organics can be expected to furnish a progressively smaller portion of the country's total consumption of fertilizer nitrogen. Since the production of natural organic materials is geared to other processes and operations their output is not capable of independent expansion. Also, these materials have, in general, the disadvantage of low plant-nutrient content and high unit cost, in comparison with chemical nitrogen products.

## BYPRODUCT NITROGEN FROM COAL AND OTHER HYDROCARBONS

Currently the Nation's output of byproduct chemical nitrogen--recovered in the forms of ammonia and chiefly ammonium sulfate and used mostly as fertilizer--is obtained essentially from bituminous coal, almost entirely in connection with the manufacture of coke. The production of such nitrogen in the first quarter of 1951 was at an annual rate of about 198,000 tons.

The nitrogen content of coking coal averages about 1.5 percent (30 pounds per ton). The quantity of nitrogen recovered at byproduct coke ovens varies from plant to plant and from year to year. Currently, it averages about 4 pounds per ton of coal carbonized. It appears unlikely that the recovery will be materially increased in the future.

About 15,000 byproduct coke ovens were in operation in the United States at the close of 1950. With operation at full capacity these ovens could produce approximately 205,000 tons of nitrogen annually. It is estimated that in 1951 there will be a net increase of about 500 in the number of operating ovens and that this will increase the potential supply of nitrogen by some 6,000 tons annually. Further expansion of the coke-oven capacity is programmed for the immediate future. Although competition from natural gas will undoubtedly force the closing of certain coal-processing operations which yield byproduct ammonia, it appears unlikely that this will have an important effect on the total supply of such ammonia.

About 95 percent of the present production of coke is in by-product plants. The remainder is manufactured in beehive ovens, which do not permit recovery of the nitrogen.

The output of coke and hence of coke-oven nitrogen is governed mainly by the output of pig iron. The supply of nitrogen from this source will continue to depend chiefly, therefore, on the production of pig iron.

Under present conditions, economical recovery of nitrogen at coke plants generally requires the use of sulfuric acid to fix the ammonia--3.5 tons of acid (basis 100 percent $H_2SO_4$) per ton of nitrogen. Approximately 617,000 short tons of acid, equivalent to 202,000 tons of sulfur, were used for this purpose in 1950. For the future it would seem wise to thoroughly explore alternative means of recovering the ammonia, as one way of conserving resources of sulfur.

The possibilities of recovering nitrogen from lignite and oil shale are briefly discussed in the preceding chapter on resources of fertilizer raw materials.

## FIXATION OF ATMOSPHERIC NITROGEN

Many types of processes have been proposed for fixation of atmospheric nitrogen by chemical methods, but only three have achieved large-scale operation. In the increasing order of their present importance these types of processes involve, respectively, (1) direct union of nitrogen and oxygen to form oxides of nitrogen and subsequently nitric acid, (2) reaction of calcium carbide with nitrogen to obtain calcium cyanamide, and (3) production of ammonia by direct combination of nitrogen with hydrogen. The economy of these processes depends chiefly on the relative cost of energy in the forms of electric power and fuel.

### Direct Union of Nitrogen and Oxygen

Fixation of atmospheric nitrogen by its direct union with atmospheric oxygen in the electric arc was the first of the commercially successful processes. This process requires, however, a very large quantity of electric power--approximately 65,000 kilowatt-hours per ton of nitrogen fixed--so that its operation has been economic only at locations close to very cheap hydroelectric power. The outstanding development of the process was in Norway, where it was operated on a large scale from 1905 to 1939. Although small plants have been operated in other countries, including one in the State of Washington from 1917 to 1927, it appears that the process has now been abandoned entirely. Aside from its extremely high requirement for power, the electric arc process has the disadvantage that calcium nitrate and

sodium nitrate, the principal fertilizer products readily obtainable thereby, are quite low in nitrogen (13 and 16 percent, respectively). It seems hardly possible that the process will again achieve commercial importance.

Recently, attention has been given to a process for the direct union of nitrogen and oxygen whereby the high temperature required for the reaction is obtained by the combustion of either manufactured or natural gas. In other respects, including the types of fertilizer products readily obtainable, the process is similar to the electric arc method. The process is still under development, but it has the possibility of ultimately producing nitric acid at a cost competitive with that of acid from synthetic ammonia. Information on the gas requirement of the process is not available.

## Calcium Cyanamide Process

Commercial manufacture of calcium cyanamide by reaction of nitrogen (obtained by the air liquefaction process) with calcium carbide (manufactured in electric furnaces from lime and coke) was commenced in 1906. Just before World War II, 55 plants were in operation in 14 countries, with a total production capacity of more than 2,000,000 tons of cyanamide per year. Subsequent to the war a few new plants have been built or are under construction. Aside from the Government plant built at Muscle Shoals, Alabama, during World War I, which was operated for only a few weeks, production of cyanamide in the Western Hemisphere has been confined to a single plant in Canada. This plant has been in operation since 1909. Over the years it has supplied a large tonnage of nitrogen for fertilizer use in the United States and elsewhere, either in the form of the cyanamide itself or of ammonium salts produced therefrom. Presently, a large portion of the plant output is converted into organic derivatives for technical and industrial purposes.

Fixation of 1 short ton of nitrogen as calcium cyanamide requires 9,000 kilowatt-hours of electricity, 4.8 tons of limestone, 1.86 tons of coke, 1.0 ton of coal, and 13.5 man-hours of labor.

As presently marketed in the United States, cyanamide contains about 21 percent of nitrogen. Cyanamide can be converted into ammonium fertilizer salts but, in general, only at such cost that the salts become more expensive than the same compounds made with nitrogen produced by the direct synthetic ammonia process. Calcium cyanamide finds some agricultural use other than as fertilizer, for example, as a defoliant for cotton and as a disinfectant for seedbeds.

Currently, there is little interest in production of calcium cyanamide for fertilizer use in the United States, except possibly in connection with its manufacture for nonagricultural purposes.

## Synthetic Ammonia Process

From its beginning in the United States in 1921, manufacture of ammonia by direct combination of nitrogen and hydrogen has expanded, very rapidly since 1940, to the point where the facilities in 1951 comprised 21 plants with an estimated total capacity of 1,616,000 short tons of nitrogen annually. In comparison, the estimated capacity in 1945 was 1,248,000 tons of nitrogen in 19 plants, whereas in 1940 it was 390,000 tons in 9 plants.

During World War II the Nation's capacity for producing synthetic ammonia was trebled by the construction for the Government of 10 plants having a total annual capacity of almost 800,000 tons of nitrogen. Of these plants, six were subsequently sold and two were leased to private companies, while one has continued in Government operation. A portion of the tenth plant was moved to another location and leased to a private company; the remaining portion is used by the Government for investigations on coal hydrogenation.

Additional capacity for production of synthetic ammonia, totaling more than 600,000 tons of nitrogen annually, was recommended or under consideration during the first 7 months of 1951. It appears certain that future expansion in production of nitrogen will be predominantly by the synthetic ammonia process.

The synthetic ammonia process has several advantages over other chemical methods of fixing atmospheric nitrogen. It can be operated wherever there are adequate supplies of fuel or of electric power. The cost of nitrogen fixed in this way is generally lower than that fixed by other methods. Owing to its high content of nitrogen (82 percent) and ease of handling, the primary product (ammonia) can be shipped at lower cost per unit of nitrogen than the primary products of other processes. It can be used directly as a fertilizer or can be readily converted into a wide variety of ammonium and nitrate salts, including such high-analysis products as ammonium nitrate and urea--33 and 44 percent of nitrogen, respectively. Ammonia is also a major chemical for industrial, technical, and other nonagricultural purposes, as indicated by the fact that its use for such purposes amounted to about 385,000 tons of nitrogen in 1950.

Of our capacity in 1951 for making synthetic ammonia, 4 percent was based on byproduct electrolytic hydrogen, 44 percent on hydrogen produced with coke, and 52 percent on hydrogen from natural gas. Hydrogen from natural gas is the basis of 80 percent of the additional capacity recommended or under consideration in 1951.

The electrolytic hydrogen used for ammonia synthesis in the United States is obtained entirely as a byproduct of the manufacture of caustic soda and chlorine. Because of the high power requirement for electrolytic hydrogen (12,700 kilowatt-hours per ton of nitrogen

fixed) its utilization for ammonia synthesis is, in general, economically feasible only where it is available as a byproduct.

At present, natural gas is the cheapest source of hydrogen for large-scale ammonia synthesis in the United States. For production of hydrogen for ammonia synthesis a total of about 43,000 cubic feet of natural gas is required per ton of nitrogen fixed. This requirement includes 15,000 cubic feet of natural gas used as fuel in processing the remainder of the gas for hydrogen production.

Preparation of hydrogen with coke requires about 1.7 tons of average coke per ton of nitrogen fixed. At present prices for coke and gas, ammonia can be produced more cheaply with natural gas than with coke. Over the long range, however, it appears that the domestic synthetic ammonia industry will be dependent primarily on coal as a basic raw material. In the light of recent investigations, direct processing of coal with the aid of oxygen appears to be a very promising means of obtaining low-cost synthesis gas. Significant developments in this field can be expected.

To compete with natural gas at 20 cents per 1,000 cubic feet for production of hydrogen, it is estimated that under present conditions coke would have to be available at $5 per ton or electric power at 0.7 mill per kilowatt-hour.

A recently developed process for making aviation gasoline yields byproduct hydrogen which at least one company is planning to use for ammonia synthesis. Utilization in this way of byproduct hydrogen from other organic chemical processes should be investigated.

## Nitrogen Fertilizer Materials

The great increase in consumption of fertilizer nitrogen as forecast for the future, poses the question of the forms in which the nitrogen should be marketed.

The chemical nitrogen materials now available for fertilizer use include mainly sodium nitrate, calcium nitrate, calcium cyanamide, ammonium sulfate, ammonium phosphate, ammonium nitrate, urea, and anhydrous ammonia, as well as certain mixtures of some of these materials. Other nitrogen compounds of such cost and characteristics as to offer promise of wide use in agriculture are not presently on the horizon. Because of their low nitrogen content (less than 23 percent) and for other reasons, it seems unlikely that consumption of the first three of the above-mentioned materials will undergo important increase.

Although ammonium sulfate and the ammonium phosphates are relatively low in nitrogen (21 percent or less) they are generally

the most satisfactory chemical nitrogen materials for use in mixed fertilizers, especially the nongranular types of mixtures commonly manufactured at present. Conversion into ammonium sulfate is the most convenient and currently the most economical way of recovering byproduct ammonia from coke manufacture. Production of ammonium sulfate in this way can be expected to increase. Ammonium sulfate will likely continue to be made from synthetic ammonia but availability of sulfuric acid may be a limiting factor. Besides supplying nitrogen, ammonium phosphate is a very desirable, highly concentrated source of phosphorus; the fertilizer grade usually contains up to about 50 percent of $P_2O_5$, and its production should be encouraged.

Anhydrous ammonia is the cheapest and most concentrated nitrogen fertilizer material. For a good many years large quantities of ammonia, mostly in solutions with ammonium nitrate or urea, have been used annually to supply a portion of the nitrogen in mixed fertilizers, whereby the ammonia is fixed by reaction with the superphosphate present in the mixtures. This practice has now advanced to the point where further increase in such use of ammonia will depend chiefly on the increase in consumption of mixed fertilizers containing superphosphate.

Use of ammonia, mostly in the anhydrous form, for application directly to the soil and in irrigation water has developed rapidly since World War II. Owing to the relatively large investment in equipment necessary for handling and distributing ammonia, further expansion in its direct utilization as a fertilizer will probably depend chiefly on the extent to which its application to the soil is organized as a service to the farmer. Currently, there is much interest in the development of such service. Direct use of ammonia should be encouraged and expanded within the limits imposed by economic considerations and by local soil conditions and farming practices.

For the future, effort should also be directed toward production of a larger portion of the Nation's fertilizer nitrogen requirements in the form of high-analysis, solid products, especially urea. Urea is the most concentrated of the solid nitrogen fertilizer materials, and it not only has important industrial and technical uses but it is also valuable as a nitrogen supplement in feeds for ruminants.

## PHOSPHATE

The Nation's phosphate fertilizer supply is derived almost entirely from phosphate rock. Of the annual consumption of available $P_2O_5$ (approximately 2 million tons in 1950) over 90 percent is in the form of products manufactured with the aid of sulfuric acid. The remainder is chiefly in the form of natural organic materials and of products made by various furnace processes.

It is estimated that our total capacity for production of phosphate fertilizers amounted to nearly 3,100,000 short tons of available $P_2O_5$ per year on June 1, 1951. Of this capacity, which is contained in more than 235 plants, 84 percent is for production of normal superphosphate and 10 percent for triple superphosphate. Additional capacity totaling more than 200,000 tons of $P_2O_5$, all in the form of triple superphosphate and other concentrated products, was recommended or under consideration during the first 7 months of 1951. It appears certain that future additions to the capacity will comprise mostly facilities for making high-analysis or concentrated products, which have the advantage of lower unit costs for handling, packaging, and transportation and for such further processing as may be required.

Lack of adequate supplies of concentrated phosphates is a major obstacle to expanded production of high-analysis mixed fertilizers, the use of which is a very important way of reducing the cost of plant nutrients to the farmer.

## PROCESSES BASED ON SULFURIC ACID

As previously mentioned, over 90 percent of the available $P_2O_5$ used as fertilizer in the United States is produced by processes involving treatment of phosphate rock with sulfuric acid. Normal superphosphate is the principal product of such processes followed by triple superphosphate, ammonium phosphate, wet-base goods, liquid phosphoric acid, and certain byproduct materials.

Manufacture of the ammonium phosphates and triple superphosphates requires the use of liquid phosphoric acid which may be produced either by the sulfuric acid process or from elemental phosphorus made by the electric-furnace or the blast-furnace process. On the other hand, manufacture of normal superphosphate and wet-base goods does not require facilities for production of liquid phosphoric acid.

The reason for the dominant position of phosphate fertilizers made with sulfuric acid is not hard to find. Plentiful supplies of low-priced sulfuric acid have been generally available in the United States for many years, and the cost of producing available $P_2O_5$ with this acid has been such as practically to preclude competition by other types of processes. The manufacture of normal superphosphate, in particular, is a simple operation and it does not require complicated equipment or technically trained personnel; it can be done economically in relatively small plants and with comparatively low capital investment per ton of available $P_2O_5$. Furthermore, the sulfuric acid processes yield products of universally high acceptability for fertilizer use. The indications are that these processes will continue to be a highly important factor in the Nation's phosphate fertilizer industry for many years to come.

The power requirement for processing phosphate rock with sulfuric acid is small and is entirely for motive purposes. Sulfuric acid is the only reagent needed.

The sulfur required to produce one ton of available $P_2O_5$ is 0.84 ton for liquid phosphoric acid or ammonium phosphate, 0.68 ton for triple superphosphate, and 0.61 ton for normal superphosphate. The sulfuric acid used in making phosphate fertilizers in the United States in 1950 corresponded to about 1,025,000 tons of sulfur for normal superphosphate and wet-base goods, 180,000 tons for triple superphosphate, and an undetermined but much smaller quantity for phosphoric acid and ammonium phosphate.

## Normal Superphosphate

For many years normal superphosphate has furnished most of the Nation's production of phosphate fertilizer. Including a small tonnage of wet-base goods, the output of normal superphosphate in 1950 amounted to 1,684,000 short tons of available $P_2O_5$. Normal superphosphate, made by simply mixing ground phosphate rock with sulfuric acid, is essentially a mixture of monocalcium phosphate and calcium sulfate. It usually contains 18 to 20 percent of $P_2O_5$. Wet-base goods is made by treating a mixture of phosphate rock and nitrogenous organic material with sulfuric acid.

As of June 1, 1951, the annual capacity for manufacturing normal superphosphate and wet-base goods in the continental United States totaled about 2,610,000 tons of available $P_2O_5$ in 202 plants. Of these plants, 72, 45, and 36 are in the South Atlantic, East North Central, and East South Central regions, respectively. The rest are widely distributed throughout the other regions of the country, chiefly in the Middle Atlantic and West Central States. Superphosphate plants in the Territories comprise one each in the Hawaiian Islands and Puerto Rico.

Owing to its relatively low content of $P_2O_5$ and the rapidly increasing demand for high-analysis phosphate fertilizers, as well as for other reasons discussed in a subsequent section of this report, it appears likely that the future will not see a very large increase in the capacity for making normal superphosphate. The capacity may even decrease substantially from the present level.

## Triple Superphosphate

Triple superphosphate is made by mixing ground phosphate rock with phosphoric acid. It is essentially impure monocalcium phosphate, and it usually contains 43 to 48 percent of available $P_2O_5$.

Production of triple superphosphate in the United States has increased markedly since World War II. The output in 1950 amounted to 309,000 short tons of available $P_2O_5$, or 2.7 times that in 1945. More than 75 percent of the output in 1950 was made with phosphoric acid manufactured by the sulfuric acid process. The remainder was produced with acid made from elemental phosphorus by the electric-furnace process.

As of June 1, 1951, the total annual capacity for making triple superphosphate amounted to approximately 315,000 tons of available $P_2O_5$, of which 77 percent was for producing the material by the sulfuric acid process. The facilities for triple superphosphate comprise seven plants using wet-process phosphoric acid—one each in Idaho, Montana, Tennessee, and South Carolina and three in Florida—one plant (the Tennessee Valley Authority, Wilson Dam, Ala.) using electric-furnace acid, and a plant in New Jersey using furnace-process spent acid from an industrial operation. The additional capacity for available $P_2O_5$ recommended or under consideration in 1951 - over 200,000 tons annually - is chiefly for triple superphosphate, mostly in Florida.

The high quality and versatility of the product and the generally favorable economy of its manufacture in comparison with that of other types of concentrated phosphates made with sulfuric acid or by other means, together with the opportunity its production offers for the recovery of import coproducts, such as uranium, vanadium, and fluorine, are considerations which appear to assure that further very large expansion in the capacity for making triple superphosphate with sulfuric acid will come about over the next few years.

## Ammonium Phosphate

The types of ammonium phosphate suitable for fertilizer use contain about 50 percent of available $P_2O_5$ and some 12 to 20 percent of nitrogen. They are manufactured by simple processes involving neutralization of liquid phosphoric acid with ammonia. They have excellent physical properties, lend themselves to a wide variety of fertilizer uses, and are readily produced with phosphoric acid made by the sulfuric acid process or from elemental phosphorus.

Although the unit cost of manufacturing available $P_2O_5$ in the form of ammonium phosphate is generally considered to be somewhat higher than that of $P_2O_5$ in triple superphosphate, ammonium phosphate is not in an unfavorable position as regards the total cost of the nitrogen and $P_2O_5$ to the farmer, in comparison with the cost of nitrogen and $P_2O_5$ in other forms, especially where transportation for long distances is involved.

Manufacture of fertilizer-grade ammonium phosphate in the United States is presently confined to a single plant in Texas, where it is made with phosphoric acid produced by the sulfuric acid process. Considerable ammonium phosphate made in the same way is imported into western United States from Canada.

Additional facilities for manufacture of ammonium phosphate are not currently in prospect. However, the position of this material as regards its quality and general usefulness, as well as its apparent economy in at least some parts of the country, is such that encouragement of expansion in its production is warranted.

## Liquid Phosphoric Acid

Apart from its use in the manufacture of triple superphosphate and ammonium phosphate, there is increasing interest in the direct utilization of liquid phosphoric acid as a fertilizer in the West. This interest is for its direct application to the soil and chiefly for addition to irrigation water. The use of phosphoric acid in these ways can be expected to grow.

Liquid phosphoric acid made with sulfuric acid is currently manufactured for fertilizer purposes by eight plants. Of these plants, five convert their output of acid entirely, or nearly so, into triple superphosphate and one makes ammonium phosphate and related products. The other two plants, one each in Idaho and Montana, manufacture chiefly triple superphosphate but also market phosphoric acid for direct use as fertilizer.

It appears that the rapidly accelerating trend toward production of high-analysis fertilizer materials and mixtures may soon place the manufacturers of normal superphosphate in a disadvantageous position and could result in the closing of many normal superphosphate plants with much financial loss to the owners. This situation could be largely avoided, however, by making liquid phosphoric acid generally available on the fertilizer market.

Ready availability of liquid phosphoric acid would permit manufacturers of normal superphosphate to increase the $P_2O_5$ content of their products to 30 percent or more—from the present level of 18 to 20 percent—by acidulating phosphate rock with mixtures of phosphoric and sulfuric acids, with little or no change in their present facilities and equipment. At the same time, it would correspondingly reduce the need for new facilities to convert phosphoric acid into triple superphosphate and other solid products at the production points of the phosphoric acid itself. The products obtained by acidulating phosphate rock with mixtures of phosphoric and sulfuric acids would be suitable for use in the preparation of most types of high-analysis mixed fertilizers, and such products

would be generally competitive with either or both normal superphosphate and triple superphosphate in many areas. Furthermore, ready availability of liquid phosphoric acid would undoubtedly do much to promote its direct combination with anhydrous ammonia, potash salts, and other materials to produce granular, high-analysis mixtures.

Production and marketing of fertilizer-grade phosphoric acid and its use in the above-mentioned ways appears to be technically and economically sound. For economic and other reasons, such acid would be made by the sulfuric acid process.

## PROCESSES BASED ON ELEMENTAL PHOSPHORUS

Elemental phosphorus is manufactured by smelting mixtures of phosphate rock, silica, and coke in electric or blast furnaces. The phosphorus can be converted readily into phosphoric acid and thence into triple superphosphate, ammonium phosphate, and other fertilizer products by methods similar to those using phosphoric acid made by the sulfuric acid process. Elemental phosphorus has certain advantages over wet-process phosphoric acid for the manufacture of such highly concentrated fertilizer products as the calcium and potassium metaphosphates, neither of which has yet achieved importance as a fertilizer material.

Elemental phosphorus is a highly important military material, and it is the basis of a large domestic industry in the manufacture of phosphates for technical and industrial purposes.

The processes for making elemental phosphorus can use directly certain kinds of low-grade phosphate rocks that do not readily lend themselves to the degree of concentration needed for treatment by the sulfuric acid processes. The use of such rocks is important to the conservation and efficient utilization of the Nation's phosphate resources.

Elemental phosphorus, being the ultimate in phosphorus concentration, can be shipped at lower unit cost than any other phosphorus product. Thus its conversion to fertilizer materials near the point of their consumption might result in cheaper $P_2O_5$ for the farmers in certain areas, even with a relatively high cost of thermal energy for manufacture of the phosphorus itself. The most promise for production of elemental phosphorus and its treatment in this way appears to be in connection with the utilization of the western phosphate deposits. However, the western phosphate area is also a potential source of large quantities of low-cost sulfuric acid from smelter fumes and gases that are being allowed largely to go to waste.

The choice between fertilizer processes based on elemental phosphorus and those based on the use of sulfuric acid depends primarily on the total cost per unit of available $P_2O_5$ at which the final products can be placed in the soil. An important factor is the cost of thermal energy on the one hand and of sulfuric acid on the other.

The energy requirements for producing 1 short ton of $P_2O_5$ in the form of elemental phosphorus by the electric-furnace process are 5,760 kilowatt-hours of electricity, 0.61 ton of coke breeze, and 16.4 pounds of carbon electrode. For one ton of $P_2O_5$ in the form of elemental phosphorus by the blast-furnace process the requirement is 2.36 tons of coke (85 percent carbon). One ton of $P_2O_5$ in the form of phosphoric acid made by the sulfuric acid process requires 2.57 tons of 100 percent sulfuric acid (0.84 ton of sulfur).

To produce a unit of $P_2O_5$ in the form of phosphoric acid (85 percent $H_3PO_4$), it was estimated recently that with the total cost by the sulfuric acid process as 100 the relative costs by the electric-furnace and the blast-furnace processes would be 129 and 138, respectively. The estimates were based on sulfuric acid at \$6.50 per ton, electric power at 2.5 mills per kilowatt-hour plus coke breeze at \$6.50 per ton plus carbon electrodes at \$0.09 per pound, and coke at \$7.50 per ton.

Facilities for manufacture of electric-furnace phosphorus comprise ten plants—including one under construction on June 1, 1951—of which all but the plant of the Tennessee Valley Authority, Wilson Dam, Ala., produce the material primarily for nonfertilizer purposes. The total capacity of these plants is estimated to be about 200,000 short tons of elemental phosphorus per year. Additional capacity is in process of installation.

Production of blast-furnace phosphorus in the United States was discontinued in 1938 when the only manufacturer switched to the electric-furnace process. Although some triple superphosphate was made, the output of this blast-furnace plant was used primarily for nonfertilizer purposes.

Chiefly because of the high costs of electric power and coke, it is not likely that elemental phosphorus for fertilizer purposes will be produced economically from the Florida and Tennessee phosphate rocks. The outlook appears to be more promising for eventual economic application of the electric- and blast-furnace processes to the western phosphates.

Further development of hydroelectric power in the West and the likelihood of increased cost of sulfuric acid, together with the adaptability of the electric-furnace process to certain types of

low-grade phosphate rock, are factors that may favor the future application of this process in the manufacture of phosphate fertilizers. The technical development of the process has reached the point where little, if any, further economy in its operating cost can be expected. The cost of phosphorus by this process will be largely governed by the cost of electric power.

Since the blast-furnace process is not in an advanced stage of technical development, there would seem to be opportunity for eventually effecting a substantial reduction in its cost of operation. The process merits thorough study and investigation, with special reference to its adaptation to utilization of the large supplies of coal which are within easy access of some of the better deposits of phosphate rock in the West.

Calcium silicate slag from manufacture of elemental phosphorus is a useful soil-liming material. It also contains a small percentage of $P_2O_5$ which appears to have fertilizer value. Ferrophosphorus for metallurgical purposes is obtained as a byproduct of phosphorus manufacture.

## FURNACE PROCESSES FOR DIRECT PRODUCTION OF PHOSPHATE FERTILIZERS

Three types of furnace processes for the manufacture of fertilizers directly from phosphate rock have been developed. These processes comprise: (1) defluorination of phosphate rock in the presence of silica and water vapor in oil-fired shaft furnaces or rotary kilns; (2) melting properly proportioned mixtures of phosphate rock and magnesium silicate minerals in electric furnaces; and (3) calcining mixtures of phosphate rock and soda ash in rotary kilns.

The defluorination process is operated in the United States by the Tennessee Valley Authority for production of fertilizer and by a private company for production of low-fluorine phosphate for livestock feedings. Two companies in this country have manufactured substantial quantities of the phosphate rock - magnesium silicate product. The soda ash process has not been operated commercially in the United States, but it has been in large-scale operation in Germany for more than 25 years.

These processes yield products in which the $P_2O_5$ is insoluble in water but is well utilized by many crops on nonalkaline soils. They are best adapted for direct application to the soil, especially as sources of $P_2O_5$ for grass and other forage crops. The economic status of the processes, in comparison with other methods of making phosphate fertilizers, is as yet rather poorly defined.

## BASIC SLAG

Basic slag, a byproduct of the manufacture of steel from high-phosphorus iron ores, is a highly important phosphate fertilizer in Europe, but its production in the United States is confined to a single plant in Alabama. This plant has an annual production of 200,000 to 250,000 tons of slag containing 8 to 12 percent of $P_2O_5$, and it is presently the only one in the country that is processing high-phosphorus iron ores. For the future, as in the past, the output of slag will depend on the extent to which such ores are utilized.

## NITRIC ACID TREATMENT OF PHOSPHATE ROCK

Nitric acid is as effective as sulfuric acid in decomposing phosphate rock, but special treatment is required to obtain fertilizer products having satisfactory physical condition. This is because of the high solubility and hygroscopicity of the calcium nitrate formed in the first stage of the operation.

For a number of years several processes for the manufacture of fertilizers by treating phosphate rock with nitric acid have been in large-scale production in Europe. The processes are of two general types. In the first type, phosphate rock is extracted with an excess of nitric acid and the solution cooled for recovery of a portion of the calcium nitrate in solid form; the residual solution is neutralized with ammonia and concentrated to obtain high-analysis, granular products consisting essentially of dicalcium phosphate and ammonium nitrate. Nitrogen-phosphate-potash mixtures are readily made by adding potash salts. Besides calcium nitrate, which is marketed as a separate material, the products include such grades as 20-20-0, 12-10-15, 12-10-20, and 15-10-20.

The second type of process avoids the separate production and marketing of calcium nitrate. The phosphate rock—nitric acid solution is treated with sufficient sulfuric acid to convert the potential calcium nitrate to insoluble calcium sulfate. The resultant slurry is then neutralized with ammonia, concentrated, and potash salts added to produce granular mixtures such as 8-16-17, 11-9-20, and 13-11-12.

The first process entirely eliminates the use of sulfuric acid but requires the marketing of approximately 40 percent of the calcium content of the phosphate rock as calcium nitrate. The second process requires only about 60 percent as much sulfuric acid as does the production of normal superphosphate. However, since the sulfuric acid used in the second process is not effective in decomposing the phosphate rock but is used only in adjusting the calcium-phosphorus ratio of the solution, other soluble sulfates such as ammonium or

potassium sulfate may be substituted for equivalent amounts of sulfuric acid. Likewise, soluble phosphates--such as phosphoric acid and ammonium and potassium phosphates--may be substituted for the equivalent sulfuric acid. Both processes require the handling of considerable volumes of corrosive solutions and slurries, so that much of the equipment must be constructed of stainless steel or other corrosion-resistent material.

These processes provide a means for solubilizing phosphate rock and producing homogeneous granular fertilizer mixtures in a single operation. They offer a major opportunity for conservation of sulfuric acid in the manufacture of fertilizers, and their adoption in the United States should be encouraged to the fullest possible extent.

## PHOSPHATE ROCK FOR DIRECT USE AS FERTILIZER

For many years, varying quantities of ground raw phosphate rock have been used directly as fertilizer in some parts of the United States, chiefly in Illinois. As reported by the U. S. Bureau of Mines, the total quantity of rock sold for this purpose increased from about 120,000 short tons in 1940 to 880,000 tons in 1950. Of the sales in the latter year, approximately 70 percent was Florida phosphate and nearly all of the remainder came from the Tennessee deposits.

Most, if not all, of the phosphate rock used for direct application is ground or otherwise prepared at or near the mines. The grinding facilities include at least 17 plants--7 in Florida, 5 in Tennessee, and 5 in the West. The total $P_2O_5$ content of the ground rock ranges from about 29 to 35 percent, and the fineness specifications from 60 to 95 percent through a No. 200 U. S. standard sieve.

The conditions under which ground phosphate rock serves as an efficient and economical fertilizer have not been clearly defined. It appears, however, that the best results are usually obtained on the heavier types of soils with applications to legumes, grasses, and other perennial crops. The material is generally recognized to be a very poor source of phosphorus for crops on alkaline soils.

## COPRODUCTS FROM PHOSPHATE ROCK

Although the commercial phosphate rocks of the world generally consist essentially of fluorine-bearing calcium phosphate, they commonly contain small percentages--often only trace quantities--of many elements. Some of the elements, notably fluorine, vanadium, and uranium, are present in such quantities and are of sufficient value and importance to justify their recovery as coproducts of the manufacture of phosphates for agricultural and other purposes.

## Fluorine

The commercial grades of domestic phosphate rock usually contain 3 to 4 percent of fluorine, and the total quantity of fluorine in the phosphate deposits of the United States is estimated to exceed 400,000,000 tons. This is many times the total fluorine content of the Nation's known deposits of fluorspar. Some 25 to 30 percent of the fluorine is volatilized and is recoverable in the processing of phosphate rock with sulfuric acid. Preparatory to its use for manufacture of elemental phosphorus, phosphate rock is customarily sintered, nodulized, or calcined, whereby about one-third of the fluorine is volatilized and can be recovered. The volatilization and possible recovery are much higher, of course, in the defluorination process.

For many years, practically the entire world supply of fluosilicates has been obtained as a coproduct of the sulfuric acid treatment of phosphate rock. Although generally sufficient to meet the requirements, the production of fluosilicates has been practiced at relatively few plants and has accounted for only a small portion of the total recoverable fluorine. Fluoridation of municipal water supplies is a new development which promises to increase very greatly the demand for fluorine compounds. Sodium fluosilicate is the most economical of the fluorine compounds that are satisfactory for this purpose.

## Vanadium

The phosphate rocks from deposits in eastern United States contain very little if any vanadium, whereas those from some of the deposits in Idaho and Wyoming are sufficiently high in this strategic element (up to 0.6 percent of V) to make its recovery economically attractive.

For about 10 years a plant in Montana has recovered vanadium as a coproduct of the manufacture of fertilizer-grade phosphoric acid by the sulfuric acid process from phosphate rock mined at Conda, Idaho. The rock contains 0.16 percent of vanadium which is substantially removed from the phosphoric acid by precipitation as phosphovanadic acid and is subsequently converted into vanadium pentoxide of a grade suitable for metallurgical purposes. The phosphoric acid is made chiefly into triple superphosphate but a portion is marketed as such for direct application to the soil.

In the manufacture of elemental phosphorus, the vanadium concentrates in the byproduct ferrophosphorus. Methods for recovering the vanadium from the ferrophosphorus have been developed.

## Uranium

Phosphate rock has recently come into the spotlight as a potential, highly important source of uranium. Despite the fact that the uranium content of the rock is generally very low (only a few hundredths of a percent at best), methods have been developed for its recovery as a coproduct of the manufacture of high-analysis fertilizers and other phosphate products by widely used processes that involve extraction of the rock with acids. The complexities of uranium production methods require that the various phosphate-manufacturing processes and plants be considered individually to determine optimum conditions for uranium recovery. Apparently, furnace methods for the processing of phosphate rock do not lend themselves to uranium recovery.

Because of the very high position of uranium as a strategic material, it is essential that the greatest possible use be made of those methods for processing phosphate rock which permit recovery of its uranium content. Supplies of acids — whether sulfuric, nitric, or other acids — must be made available to meet the requirements of these processes for production of the maximum usable quantities of the phosphate products. By far the greater portion of such production will be in the form of concentrated fertilizer materials which pose important problems of their efficient and economical utilization.

# POTASH

Nearly all of the commercial fertilizer potash used in the United States (1,105,000 short tons of $K_2O$ in the year ended June 30, 1950) is derived from brines and chiefly water-soluble minerals. The remainder is mostly, if not entirely, in the form of cement-kiln dust, distillery byproducts, and natural organic materials. In addition to the consumption as fertilizer, more than 70,000 tons of $K_2O$ as the chloride and sulfate are used annually for technical and industrial purposes. Of the total potash used as fertilizer, nearly 80 percent is in the form of almost pure potassium chloride containing 60 percent or more of $K_2O$.

As of March 1951, it is estimated that the total capacity for production of potash in the United States amounted to 1,350,000 tons of $K_2O$ per year, mostly in the form of potassium chloride. This capacity was nearly all in two plants (one each in California and Utah) that produce potash from lake brines and three plants in New Mexico that produce it from water-soluble minerals. Most of the capacity is in the New Mexico plants. There are small capacities for production of potassium chloride from brine wells by a plant in Michigan, as well as for recovery of potash-bearing cement-kiln flue dust at a plant in Maryland and of distillery-waste potash

at a plant in Pennsylvania. Natural organic materials containing small percentages of potash are derived from many sources. Two new plants with a total initial capacity of about 370,000 tons of $K_2O$ per year are under construction in New Mexico and are expected to be in operation by 1953. Additional new operations and expansions of existing facilities are under consideration.

## POTASH FROM LAKE BRINES AND WATER-SOLUBLE MINERALS

Over 95 percent of the potash produced in the United States comes from the brines of Searles Lake, Calif., and the deposits of highly soluble minerals — sylvite (KCl) and langbeinite ($K_2SO_4 \cdot 2MgSO_4$) — in New Mexico. Modern methods have been adopted for mining and processing the minerals and for recovering potash from the brines. The methods include flotation, fractional crystallization, and applications of the principles of base exchange, double decomposition, and the phase rule. Potassium sulfate and principally potassium chloride are produced from the lake brines, potassium chloride from the sylvite ore, and potassium sulfate and sulfate of potash-magnesia from the langbeinite ore.

The processing requirements for production of potash salts from the brines and soluble minerals are chiefly water for the refining operations and electric power for motive purposes.

The growing of tobacco requires potash chiefly from nonchloride sources. Nonchloride potash is also desirable, though not highly essential, for certain other crops — notably potatoes and citrus. The least expensive of such forms of potash is usually the sulfate, but, even so, the wholesale cost of potash as the sulfate is nearly twice that of chloride potash. At present, only about 8 percent of the domestic consumption of agricultural potash is in the form of sulfate salts (potassium sulfate and sulfate of potash-magnesia). In addition to the production from langbeinite ore and Searles Lake brine, potassium sulfate is manufactured from potassium chloride and sulfuric acid.

Potassium sulfate has never been in abundant supply. Very much larger quantities would be used with considerable benefit to American agriculture if its price were more nearly that of potash in the chloride form. The best opportunity for solving this problem appears to lie in the development of more economical methods for producing the sulfate directly from the soluble potash minerals of the western deposits.

Large tonnages of polyhalite, a complex mineral composed of the sulfates of potassium, calcium, and magnesium, are known to occur in and adjacent to the present potash mines in New Mexico, as well as in other parts of the field. Methods have been developed experimentally for the recovery of potash salts from polyhalite but

they have not been put into operation, chiefly because of the current adequacy of reserves of the more easily and economically processed sylvite and langbeinite ores. A very desirable feature of most of the methods is that they yield high-grade potassium sulfate and sulfate of potash-magnesia. Recovery of potash from polyhalite should be encouraged within the limits of its economic possibilities, as a means for increasing the supply of potassium sulfate and for effecting more efficient utilization of our potash resources.

## POTASH FROM OTHER SOURCES

The United States has vast reserves of potash in water-insoluble minerals and rocks, such as the greensands of the eastern seaboard, Georgia shales, Wyoming leucite, Utah alunite, potash feldspars, and porphyry copper mine tailings. Over the years, much work has been done on these materials, and technically feasible methods of recovering the potash have been developed. The methods generally involve the recovery of coproducts, but none has achieved sustained operation on a commercial scale.

At present the prospects are not bright for the treatment of these materials to produce potash salts, either alone or with marketable coproducts, in competition with potash from brines and soluble minerals. They constitute, nevertheless, a huge potential source of potash which may eventually lend itself to economical exploitation by methods and techniques as yet undiscovered or little known.

The blast-furnace and cement industries are potential sources of considerable potash, small percentages of which are present in the raw materials. The potash is largely volatilized during the manufacturing operations and may be recovered by known methods. However, the recovery of such potash is seldom economic under present conditions.

Sea water, a potential inexhaustible source of potassium, contains an average of about 0.05 percent of $K_2O$. A process for recovery of the potash, which makes use of a regenerable organic precipitant, is reported to have been developed in Norway on a pilot-plant scale. The efficiency of the recovery is approximately 70 percent. It has been estimated that with a selling price of about $1.00 per unit of $K_2O$, operation of the process would be economically feasible. This is about double the current wholesale price of potash in the United States. Further development of this process or the application of other methods may eventually bring sea water into a competitive position with other sources of potash.

## SULFUR

The requirement for sulfur in the domestic fertilizer industry is almost entirely for the processing of phosphate rock and the manufacture of ammonium sulfate, where it is used in the form of sulfuric acid. The consumption of acid for these purposes in 1950 was equivalent to approximately 1,615,000 short tons of sulfur. An additional though relatively quite small quantity of sulfur as sulfuric acid was used in making other fertilizer products, including liquid phosphoric acid for direct application to the soil, ammonium phosphates, potassium sulfate, and the sulfates of magnesium, copper, manganese, and zinc.

Sulfur-bearing materials, such as gypsum, elemental sulfur, sulfuric acid, and sulfur dioxide, are used for the amelioration of alkali soils in the West, and there is some use of gypsum as a source of plant-nutrient sulfur in other parts of the country. The materials used for these purposes in 1950 contained the equivalent of about 90,000 tons of sulfur, of which more than two-thirds was in the form of gypsum.

Additional agricultural uses for sulfur include the manufacture of fungicides, insecticides, and other pesticides. The equivalent quantity of sulfur used for such purposes in 1950 amounted to about 200,000 tons.

From the standpoint of plant nutrition, sulfur is as important as nitrogen, phosphorous, potassium, and the other nutrient elements. For many years, however, very large quantities of sulfur have been applied to the soil as a constituent of commercial fertilizers — such as normal superphosphate and ammonium sulfate — that are primarily used for their content of other nutrient elements. In 1950, for example, more than 1,250,000 tons of sulfur were applied in this way. Besides an undetermined but very large quantity brought down from the atmosphere by rainfall, probably more than 600,000 tons of sulfur were also supplied in the form of farm manures, liming materials, pesticides, soil amendments, and other materials.

Because of the large quantities of sulfur applied in these ways — probably greatly in excess of the crop needs for nutrient sulfur — there is little or no evidence of soil deficiencies of sulfur except in a very few areas. Thus the use of fertilizers for the specific purpose of supplying nutrient sulfur is very limited. It is certain, however, that deficiencies would soon appear in some important agricultural sections if sulfur were substantially eliminated from commercial fertilizers.

The sulfur problem in fertilizers is primarily one of obtaining the supplies of raw materials needed to make sulfuric acid for processing phosphate rock and manufacturing ammonium sulfate.

No new fertilizer processes that will require large quantities of sulfuric acid are on the horizon. On the other hand, methods of making phosphate fertilizers without sulfuric acid, such as the nitric acid process, are expected to come into considerable practice. It may well be, however, that the use of such methods will not keep pace with the increase in consumption of phosphate fertilizers.

The commonly-used processes for making sulfuric acid are highly efficient and easily operated and have been long established. The capacity for making acid is generally adequate to meet present requirements, and normally it can be readily increased as the need for more acid arises.

It should be emphasized again that the pressing problem is the provision of adequate supplies of sulfur in forms suitable for economical conversion into acid.

## CALCIUM

Approximately 14.6 million short tons of calcium oxide (CaO) in the forms of commercial fertilizers (3.25 million tons) and liming materials (11.35 million tons) are applied annually to the soils of the United States. Superphosphate is the principal source of calcium in fertilizers, but substantial quantities are also supplied as limestone, chiefly the dolomitic variety, which is widely used as a neutralizing agent in the preparation of nonacid-forming mixed fertilizers. Other sources of commercial-fertilizer calcium are principally gypsum and ground raw phosphate rock.

High-calcium and dolomitic limestones furnish by far the greater portion of the calcium applied as agricultural liming materials. Other sources include marl, shells, blast-furnace and other industrial slags, and a wide variety of byproduct and waste materials. Limestone is generally prepared for agricultural use by crushing and grinding. Limited quantities are applied to the soil in the forms of burned lime and hydrated lime.

Agricultural limestone is produced by hundreds of plants distributed throughout the country, chiefly in the acid-soil areas of the East, South, and Middle West. The operations range from very small plants to those producing many thousands of tons annually. Large quantities of agricultural limestone are produced in connection with the preparation of stone for concrete aggregates, road metal, ballast, and many other purposes. Much of the agricultural limestone is transported in spreader trucks which apply it directly to the soil.

Since large resources of easily accessible liming materials occur in most agricultural areas, the problem of adequate supplies

of calcium for American agriculture is principally one of providing the relatively simple processing facilities in locations to supply most economically the farmers' needs. Thus far, the production of agricultural liming materials has been generally sufficient to meet the demands.

## MAGNESIUM

The agricultural use of magnesium is much smaller than that of calcium. Commercial fertilizers and liming materials, respectively, supply about 0.25 and 2.2 million short tons of magnesium oxide ($MgO$) to the soil annually. Dolomitic limestone, used as a neutralizing agent in the preparation of nonacid-forming mixtures, supplies 50 percent or more of the magnesium in mixed fertilizers. Other sources of commercial-fertilizer magnesium include natural organic materials, superphosphate, magnesia, magnesium sulfate, and especially sulfate of potash-magnesia.

The magnesium applied as agricultural liming material is predominantly in the form of dolomitic limestone. Blast-furnace and other industrial slags supply small quantities. Dolomitic limestone, like the high-calcium material, is widely distributed over the United States, but in more restricted areas and probably in smaller quantity. Dolomitic limestone for agricultural use is produced by many plants and with the same type of equipment as that required for high-calcium limestone. The supply problems for both materials are generally similar.

Relatively small quantities of magnesia are used in mixed fertilizers. This material is produced by calcining magnesite, brucite, and dolomite, and from well brines and sea water. Plants for recovery of magnesia from sea water are located in California, New Jersey, and Texas.

Magnesium sulfate is produced from well brines, magnesia, and dolomite, and has been made commercially from serpentine. The anhydrous compound, of which calcined kieserite is one form, is preferred for mixed fertilizers.

The Nation's resource of sulfate of potash-magnesia is in the langbeinite ore of the New Mexico potash deposits.

Fertilizers containing some 20 percent of $P_2O_5$ and 15 percent of $MgO$ have been manufactured in California and Washington by fusing phosphate rock with serpentine or olivine.

## TRACE ELEMENTS

The principal trace elements used as commercial fertilizers in the United States are boron, copper, manganese, and zinc. Facilities for producing the plant-nutrient forms of these elements are generally adequate for the present relatively small demand. However, recognition of the need for greatly increased use of trace elements in many parts of the country is growing rather rapidly, so that problems of supply may arise in the future if a large agricultural requirement is superimposed on the demands for metallurgical and industrial purposes. This may happen with copper and zinc and especially with manganese.

The Nation's consumption of boron for agricultural use is supplied from the large reserves in the West. The consumption is mostly in the form of borax produced directly from the mineral deposits and lake brines of California. Borax is applied directly to the soil as a separate material and is included in many mixed fertilizers. In some parts of the country it is a rather general practice to add 5 pounds of borax per ton to all mixed fertilizers; the quantity may be as high as 100 pounds per ton for certain crops, for example, beets.

For plant-nutrient purposes, copper, manganese, and zinc are applied chiefly in the form of the sulfates, usually either directly to the soil as separate materials, in mixed fertilizers, or as foliage sprays.

## MIXED FERTILIZERS

In the year ended June 30, 1950 the consumption of mixed fertilizers in the United States and Territories totaled 12,309,000 short tons containing 2,862,000 tons of primary plant nutrients (N, available $P_2O_5$, and $K_2O$). Mixtures supplied 67 percent of the fertilizer and 70 percent of the primary nutrients used in that year. Similar proportions were supplied in previous years.

Mixed fertilizers are manufactured in approximately 1,200 plants distributed in all but four of the States. The capacities of these plants, which range from a few tons to more than 100,000 tons per year and are operated by more than 800 companies and individuals, are estimated to total about 21.5 million tons.

The types of mixed fertilizers produced are many and varied. They include solids and liquids, powders, and granules, and a host of specialty products intended primarily for nonfarm consumption. The materials used in their manufacture range from gases and liquids to solids that differ greatly in their chemical and physical characteristics.

Currently, the manufacture of mixed fertilizers in the United States generally involves the relatively simple operation of mixing the required quantities of dry, solid fertilizer materials--usually with addition of anhydrous ammonia or, more frequently, aqueous solutions of ammonia and nitrogen salts— with conditioning agents, neutralizing materials (dolomitic limestone), and such filler as may be necessary to adjust the concentration of total nutrients to the desired level. The product of this operation is commonly a powdery material.

Production of granular mixtures, which has received much attention in recent years, is gathering momentum, and it can be expected that a progressively larger portion of the output of mixed fertilizers will be in granular form. Granulation hinders or prevents segregation of the constituents of the mixture, reduces caking, and facilitates application of the fertilizer to the soil; together with packaging in moisture-proof bags, it makes possible the preparation of high-analysis mixtures containing large proportions of hygroscopic salts like ammonium nitrate and urea.

The operations and equipment for making mixed fertilizers vary considerably from plant to plant. They range from simple types requiring much hand-labor to plants that are highly mechanized. In recent years, the labor problem has forced manufacturers to give increasing attention to plant mechanization. Studies by the Bureau of Labor Statistics, U. S. Department of Labor, indicate the progress in this respect. Thus, the index of man-hours of total factory labor expended in the production of a ton of mixed fertilizer was 81.1 in 1948, as compared with 100 in 1939. Further reduction in the labor requirement will be made.

About 950 different grades of mixed fertilizers are sold in the United States. Some 80 grades supply more than 95 percent of the total tonnage of mixtures, while approximately 40 percent is supplied by five grades. Many of the States publish lists of recommended grades, and a number prohibit the registration and sale of nonrecommended grades. Restriction of the number of grades of mixed fertilizers makes for simplification of manufacturing operations, improvement of plant efficiency, lower production and marketing costs, and more effective utilization of supplies of fertilizer materials. It also aids regulatory operations and simplifies the farmer's choice and use of fertilizers.

As shown in table 4, the average content of primary plant nutrients in mixed fertilizers increased from 18.3 percent in 1933-34 to 23.2 percent in 1949-50. While this increase (27 percent) is highly important, an even larger increase is both technologically and economically feasible. This is because the nutrient concentration of mixed fertilizers has not generally kept pace with that of the materials from which they are made,

with the result that the average mixture contains a high percentage of added inert filler (principally sand). The total quantity of such filler used in 1950 was approximately 950,000 tons. Its use can be substantially eliminated, with important reductions in the unit costs of the plant nutrients to the farmer, simply by raising the grade of the mixtures.

Mixed fertilizers, in general, also contain considerable dolomitic limestone, which serves as a filler, as a source of nutrient magnesium, and chiefly as an agent to render the mixtures nonacid-forming in the soil. It is estimated that the total quantity of dolomitic limestone used in these ways in 1950 was of the order of 700,000 tons. Addition of dolomitic limestone to mixed fertilizers serves a useful purpose in areas that do not have adequate farm-liming programs. Since the objectives of such addition can be accomplished more economically and effectively by proper soil liming, the practice of adding limestone to fertilizer mixtures should be discontinued as rapidly as local soil-management practices will permit.

One of the most promising opportunities for lowering the cost of plant nutrients to the farmer is by increasing the concentration of mixed fertilizers, thereby reducing transportation, handling, storage, and bagging costs per unit of nutrients. It is estimated that a saving of at least $20 per ton of plant nutrients could be effected by increasing the concentration of the average mixture from 23 percent (the present level) to 30 percent. Higher concentrations would permit additional savings. Insufficient supplies of concentrated phosphates and the poor physical properties of the concentrated nitrogen materials (ammonium nitrate and urea) are among the factors that have retarded the general attainment of the higher levels of nutrient concentration in mixtures. These obstacles will be progressively removed by current and future expansions in production of concentrated phosphate materials and by further developments in the manufacture of granular mixtures.

## RECOVERY OF FERTILIZER MATERIALS FROM INDUSTRIAL AND MUNICIPAL WASTES

Many kinds of industrial and municipal wastes find their way into use as commercial fertilizers. Included among these materials are oilseed meals, tung and castor pomaces, cocoa wastes, animal and garbage tankages, process tankages (made from wool, leather, fur, and other nitrogenous wastes), fish scrap and meal, dried blood, and sewage products. However, owing in part to the fact that the oilseed meals and the animal and fish products are generally much more valuable as animal feeds, the total quantity of primary plant nutrients (N, $P_2O_5$, and $K_2O$) supplied by the above-named materials probably does not exceed 100,000 tons per year.

The plant-nutrient content of these materials is generally low — less than 10 percent of $N + P_2O_5 + K_2O$ — and the unit cost is usually excessively high in comparison with that of inorganic fertilizers. Also, the nutrients are often in forms that are of inferior quality.

According to the U. S. Public Health Service, the Nation has more than 11,800 municipal sewer systems which serve a total of about 92 million people. Of these systems, however, only 56 percent — serving some 56.5 million people — have sewage treatment plants. Local use as a fertilizer and soil amendment is made of the sludge from many of the treatment plants. Other means of disposing the sludge include incineration and, principally, dumping. At a few of the plants the material is processed in various ways for shipment as commercial fertilizer.

Though much attention has been given to the utilization of sewage products as fertilizer, the problem is still far from being solved. A major difficulty is the generally low nutrient content which commonly limits the use of such products to areas adjacent to the treatment plants. The health hazard of certain kinds of the products in the growing of food crops is also a deterrent to their use. Increased effort should be made not only to effect more complete utilization of sewage for fertilizer purposes but also to develop products that are better suited for this use, even though such use will likely, for economic reasons, be generally restricted to local areas.

Although industrial and municipal wastes can be expected to supply at best only a small portion of the Nation's plant-nutrient requirements, their utilization is important as a conservation measure and especially to reduce stream and atmospheric pollution and other health hazards.

## VALUE OF FERTILIZER PLANTS

Fertilizer-manufacturing plants may be grouped in three categories: (1) those that process the raw materials into primary products, such as ammonia, superphosphates, and potash salts; (2) those that transform the primary products into compounds that are more generally usable, for example, the ammonia-conversion products; and (3) those for blending materials into mixtures.

It is estimated, admittedly incompletely, that the reproduction cost of the Nation's facilities in these categories approaches 809 million dollars, while the actual value — allowing for depreciation because of age, usage, and obsolescence — is nearly 617 million dollars (table 10). The reproduction costs are based on information from several sources, chiefly estimates by engineering firms

TABLE 10. - Estimated value of fertilizer plants in the United States, as of July 1951

| Kind of plant | Depreciated value | Reproduction cost |
|---|---|---|
| | 1,000 dollars | 1,000 dollars |
| Synthetic ammonia 1/ | 243,000 | 324,000 |
| Ammonia conversion 2/ | 68,950 | 84,400 |
| Superphosphates 3/ | 100,000 | 125,100 |
| Potash | 80,000 | 87,500 |
| Mixed fertilizer | 125,000 | 187,500 |
| Total | 616,950 | 808,500 |

1/ The data relate only to the portion of the plant capacity devoted to production of ammonia for use as fertilizer.

2/ Facilities for converting ammonia into fertilizer products, including byproduct ammonium sulfate.

3/ Normal and triple superphosphates.

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Table 11. - Estimated United States production, foreign trade, and apparent consumption of commercial fertilizer nitrogen, year ended June 30, 1951

| Item | Nitrogen | |
|---|---|---|
| | Quantity | Portion of total |
| | Short tons | Percent |
| Production | 1,098,000 | 79 |
| Imports | 289,000 | 21 |
| Total supply | 1,387,000 | 100 |
| Apparent consumption | 1,285,000 | 93 |
| Exports | 102,000 | 7 |
| Total distribution | 1,387,000 | 100 |

U. S. Department of Agriculture

currently engaged in construction of the several types of plants. The depreciated values are based largely on the known conditions of the plants presently in operation.

The estimates do not include the large investment in facilities for mining and concentrating phosphate rock; producing sulfuric acid for manufacture of superphosphates and other fertilizers; quarrying and processing limestone for agricultural purposes; production of trace-element compounds; and recovery and processing of fertilizers from wastes and byproducts, except byproduct ammonium sulfate. Also excluded are the investment in special equipment for transporting and distributing fertilizers and fertilizer materials, such as tank cars for shipping liquid ammonia and facilities for its local storage. With inclusion of these investments, the total reproduction cost of all facilities for fertilizer production would likely be well over a billion dollars.

In addition to the plants in operation in July 1951, new facilities having a total estimated value of 146 million dollars were either under construction or recommended for construction.

## VI. IMPORT-EXPORT CONSIDERATIONS OF FERTILIZERS AND FERTILIZER RAW MATERIALS

### NITROGEN FERTILIZERS

The United States is relatively self-sufficient in supplies of the three primary plant nutrients — N, $P_2O_5$, and $K_2O$. In the case of nitrogen, however, imports exceeded exports in each of the years ended June 30, 1949 to 1951. The importance of the foreign trade is indicated by the data of table 11 as estimated for the fiscal year 1951.

The imports of fertilizer nitrogen come chiefly from Chile and Canada, with the larger portion from the latter country. From Canada, the United States obtains ammonium nitrate, ammonium sulfate, ammonium phosphate, and calcium cyanamide, mostly supplied to the North Central and Western States, the areas nearest to the Canadian plants. Chile supplies nitrogen in the form of natural sodium nitrate. Per unit of nitrogen, Chilean nitrate is higher in price than the synthetic products. If this price differential is continued it is probable that smaller quantities of nitrogen will be imported from Chile in the future. Small quantities of calcium nitrate are imported from Norway and of other nitrogenous fertilizers from Germany, the Netherlands, and Belgium. It is not expected that important quantities of nitrogen will normally be imported from Europe.

Since World War II, exports of nitrogen from the United States have been largely to the military occupied areas and to countries coming within the scope of activities of the United Nations Relief and Rehabilitation Administration and, subsequently, the Economic Cooperation Administration. Owing to the disturbed status of international politics and to the efforts of countries throughout the world to produce their own requirements of fertilizer nitrogen, the future of nitrogen exports from the United States is difficult to predict. Under reasonably normal conditions, however, it appears unlikely at best that exports will undergo any large expansion.

Europe is the major nitrogen producing and consuming area of the world. On a crop-acre basis the rate of consumption in many Western European countries far exceeds that of the United States. During the next 25 years, European consumption is expected to increase considerably, but production facilities should be sufficient to supply the fertilizer needed.

It is expected that considerable progress will be achieved during the next 25 years in increasing the use of nitrogen on crops. In the free-world areas outside the United States the 1949-50 consumption amounted to approximately 2.6 million short tons of nitrogen. It is roughly estimated that by 1975 the consumption will reach 5 million tons annually.

In a large portion of South America the requirements for fertilizer nitrogen can probably be supplied most economically by Chilean nitrate. For the rest of the continent, provision of nitrogen in its most economical forms will involve considerations of facilities for its fixation from the atmosphere. Production of nitrogen fertilizers in this way is not an insurmountable problem in any country that has adequate supplies of coal or other carbonaceous materials or of hydroelectric power.

The United States will be able to aid countries that need additional nitrogen-producing facilities, by providing technical assistance and know-how in building plants, starting operations, and training personnel. Also, we can supply much, if not all, of the necessary equipment and machinery, partly on a commercial basis and to some extent under various assistance programs.

## PHOSPHATE FERTILIZERS

The countries of the free world outside the United States consumed phosphate fertilizers equivalent to about 3.6 million short tons of $P_2O_5$ in 1949-50. During the next 25 years it is expected that consumption in these countries will increase to somewhere in the neighborhood of 6 million tons annually.

The phosphate required for fertilizer purposes is obtained mostly from phosphate rock, of which the United States has a large reserve. For many years the United States has exported large quantities of phosphate rock and at the same time has imported small amounts. In 1950 the exports totaled 1,832,000 long tons. Imports amounted to only 87,000 long tons, mainly from the Netherlands West Indies. Due to its low fluorine content, the West Indies rock is used largely for poultry and stock feed, rather than for fertilizer.

Outside the United States, European countries are the largest consumers of phosphate rock, most of which is obtained from mines in Tunisia, Algeria, and French Morocco. The North African deposits are quite large and it may be expected that Europe will continue to meet the bulk of its requirements from this source. In addition, North Africa supplies much phosphate rock to other African countries and to Asia. Other deposits include those in Egypt and the Soviet Union.

Japan, Australia, and New Zealand are the principal consumers of phosphate rock in the Far East. Japan's supplies come from several sources, notably the United States, Africa, and certain Pacific islands. Australia and New Zealand obtain phosphate rock almost entirely from islands of the Pacific and Indian Oceans. As consumption increases and production from the rather limited island deposits reaches its maximum — perhaps during the next 25 years — it may be expected that the countries of the Far East will turn to North Africa or the United States for an increasing proportion of their supplies, the source depending on relative prices and the availability of appropriate foreign exchange required in payment. One should not discount, however, the possibility — by no means remote — of the discovery of additional important deposits of phosphate rock in the Far Eastern area.

The world consumption of phosphate fertilizer is predominantly in the form of superphosphate made by acidulating phosphate rock with sulfuric acid. At present the inadequate supply of sulfur and sulfuric acid limits the quantity of superphosphate that can be produced. In some European countries phosphate rock is acidulated with nitric acid, but this practice has not yet been adopted in the United States. For the future, it appears that supplies of sulfuric acid will not continue to be a major problem in most countries and that increasing quantities of phosphate fertilizer will be made without the use of this acid.

Aside from phosphate rock, the United States exported in the year ended June 30, 1951, fertilizers and fertilizer materials containing 83,000 short tons of $P_2O_5$, most of which was in the form of superphosphates and the remainder as nitrogenous phosphates and mixed fertilizers of various kinds. Likewise, the imports totaled 42,000 tons of $P_2O_5$, mostly as ammonium phosphates from Canada.

The exports went chiefly to Canada, Korea, and Cuba. In relation to the production (about 2,226,000 tons of $P_2O_5$) the foreign trade was quite small.

For the future, the prospects are that imports of phosphate fertilizers into the United States will show no considerable increase. It appears, however, that the rapidly growing, domestic production of concentrated products, together with the developing demand for phosphate fertilizers in nearby areas such as Latin America, may favor expansion of the export trade.

## POTASH FERTILIZERS

In the year ended June 30, 1951 the United States imported more potash than was exported. In terms of $K_2O$, imports were estimated at 203,000 short tons and exports at 67,000 tons. The exports were principally to Canada, Cuba, and Brazil and the imports were mainly from Germany, France, and Spain. The imports were used mostly on the East Coast, the area farthest from the New Mexico mines. It is believed that, in general, European potash can compete economically with the American material only along the coast where there is a transportation advantage for the European product. On the other hand, exports from the United States will probably continue at a fairly substantial level since the domestic product is competitively priced and modern production methods and equipment will likely cause it to remain so.

Potash consumption in the free world, not including the United States, is expected to increase to around 3.5 million short tons of $K_2O$ by 1975, compared with 2.2 million tons in 1949-50.

Production from the vast reserves of potash in Germany, and to some extent in France and Spain, will supply the needs of most of the world outside the United States. The fast developing United States industry is expected to be able to meet the growing domestic requirements and provide for some exports.

# VII. TRANSPORTATION AND CONTAINER PROBLEMS IN THE FERTILIZER INDUSTRY

Transportation problems are of major concern in the manufacture and use of fertilizer, which, with its raw material ingredients, is now one of this country's principal freight commodities. In 1949 the railroads transported 15,562,928 short tons of fertilizer and fertilizer materials and 17,685,149 tons of phosphate rock, or a total of 33,248,077 tons of fertilizer and phosphate rock. The

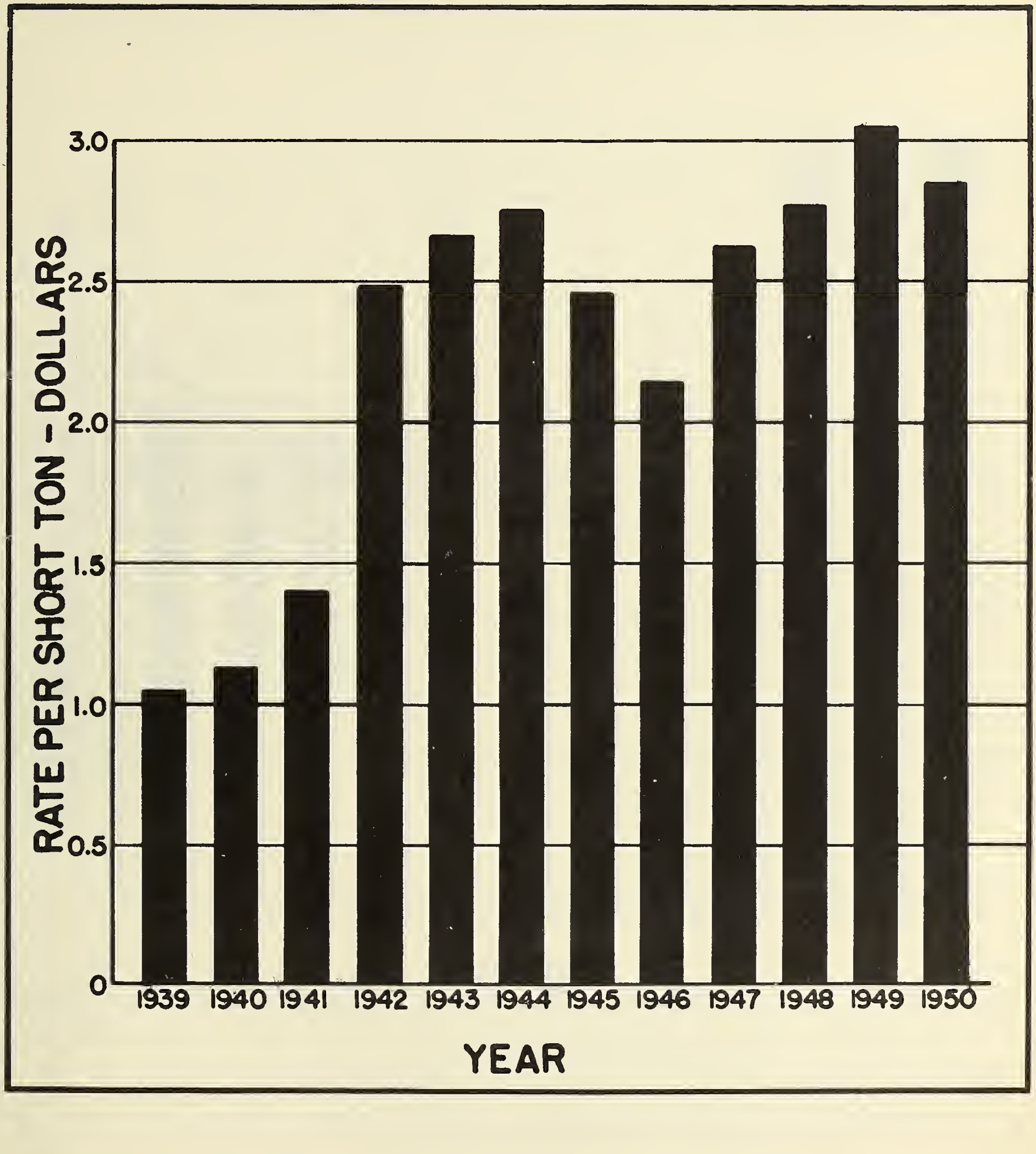


Figure 4. - Average rail rate on phosphate rock in the United States, 1939 - 1950.

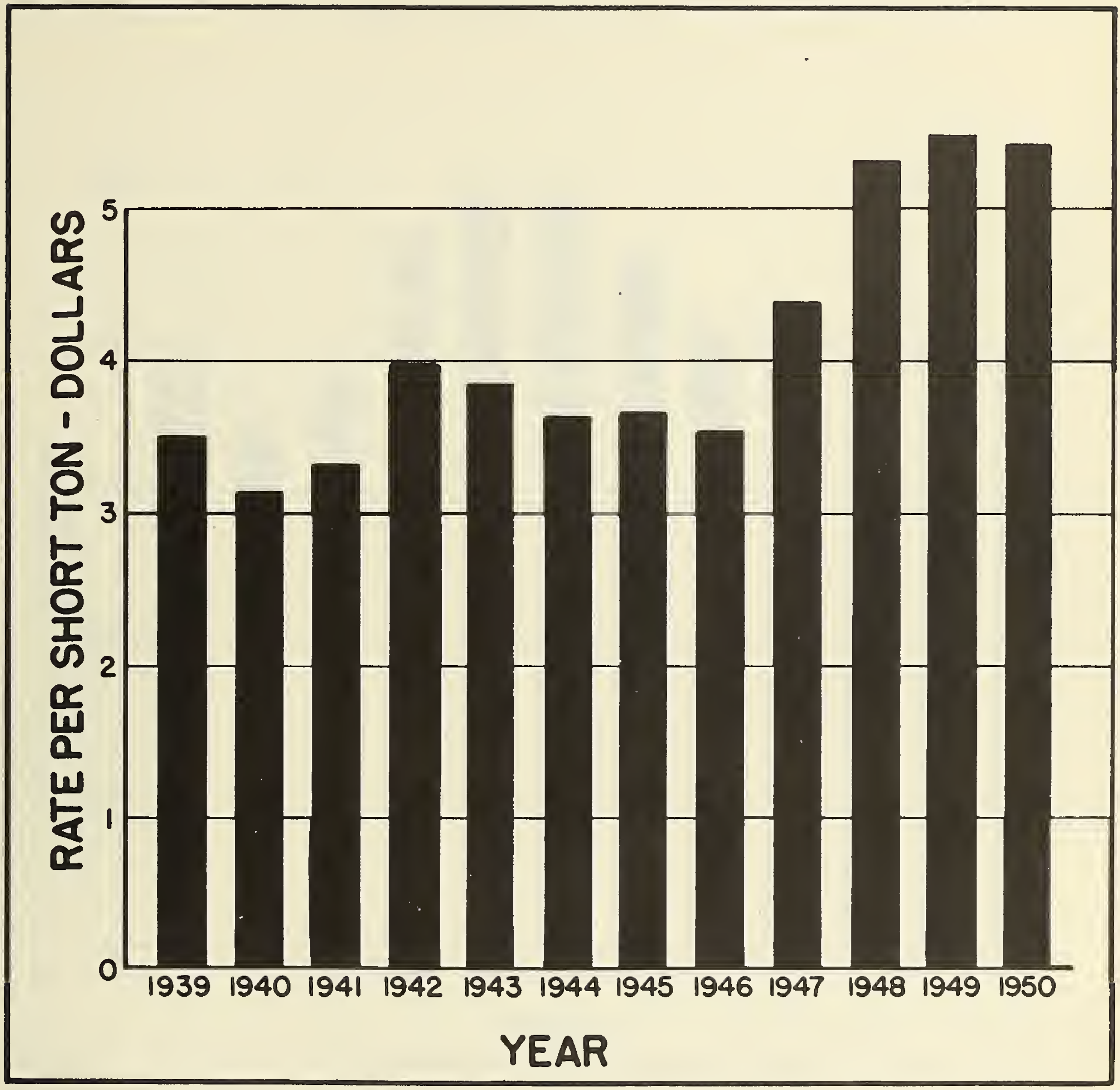


Figure 5. - Average rail rate on fertilizer in the United States, 1939 - 1950.

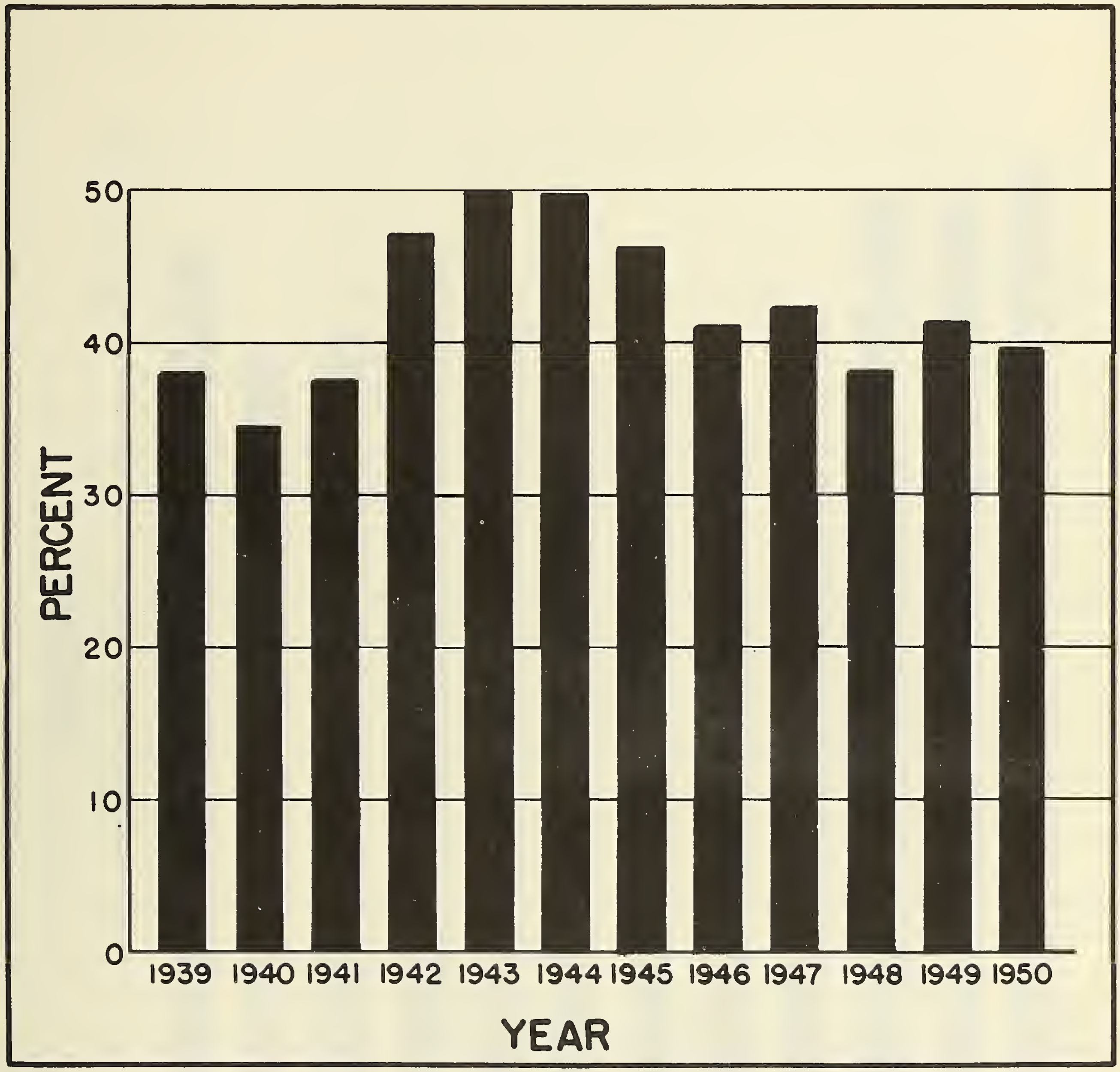


Figure 6. - Rail freight cost as percentage of phosphate-rock value at destination in the United States, 1939 - 1950.

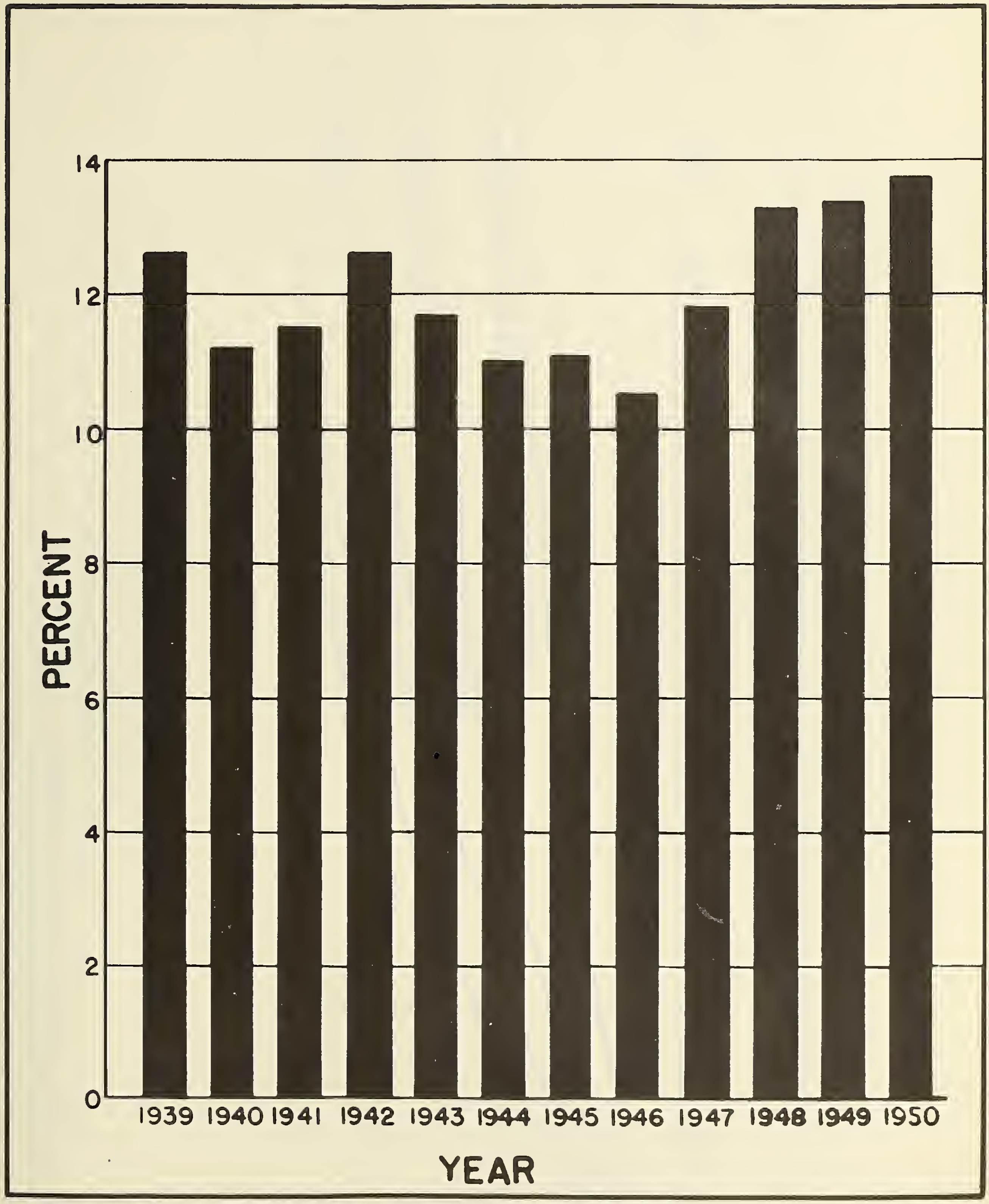


Figure 7. - Rail freight cost as percentage of fertilizer value at destination in the United States, 1939 - 1950.

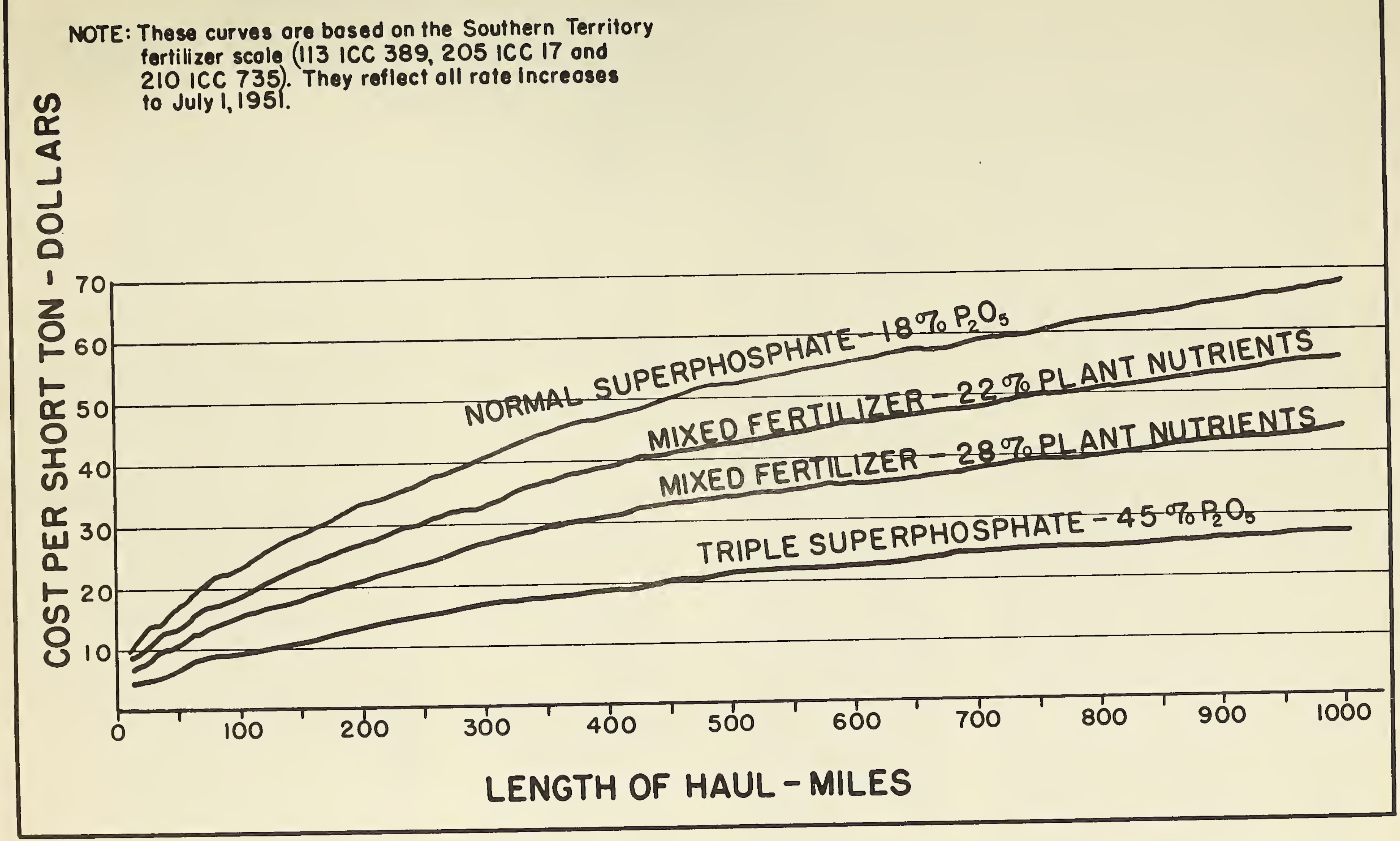


Figure 8. - Rail transportation costs in the United States per ton of plant nutrients for different fertilizer nutrients.

total quantity of fertilizer and fertilizer materials moving on the inland and coastal waterways of the United States was 5,135,031 tons, of which about 2,950,000 tons were phosphate rock.

Statistics of truck movements are not available. However, trucks are virtually the only means of delivering fertilizer to the farm. Approximately 500,000 for-hire motor vehicles serving farm areas and 2,500,000 farmer-owned trucks hauled to points of final use virtually all the 18,346,000 tons of fertilizer consumed in the year ended June 30, 1950. Establishment in recent years of many motor-competitive, rail fertilizer rates emphasizes the growth of importance of this method of transport for long intercity hauls. Testimony by witnesses for the fertilizer industry before the Interstate Commerce Commission in May 1951 described the rapidly expanding volume of fertilizer transported by highway carriers.

## TRANSPORTATION COSTS AS PART OF FERTILIZER PRICES

Transportation costs constitute an important part of the price of commercial fertilizers on the farm. Figures 4 and 5 show that since 1939, average rail freight charges per ton on phosphate rock and fertilizer have trended upward. Figures 6 and 7 indicate that rail freight costs were a larger proportion of the destination wholesale values of phosphate rock and fertilizer in 1950 than in 1939.

During the period 1939 to 1950, transportation costs accounted for 10 to 14 percent of the value of fertilizer at its destination (figure 7). This represents only transportation on the final product, and does not allow for the fact that additional transportation costs were paid on the raw materials for fertilizer manufacture. Figure 6 shows that, during the same period, transportation costs amounted to 35 to 50 percent of the value of phosphate rock at its destination. Transportation costs, without question, strongly influence the economical use of fertilizer.

## TRANSPORTATION ADVANTAGES OF INCREASED CONCENTRATION

From a transportation standpoint, one of the most significant recent developments in fertilizer manufacturing is the rapidly expanding production of higher-analysis fertilizers. The fertilizer industry anticipates a steady, substantial growth in production and use of the higher concentrations, especially of triple superphosphate. In 1900 the average plant-nutrient content of mixed fertilizers consumed in the United States was 13.9 percent. By 1949 the plant-nutrient content had reached 22.5 percent. At the same progression, the proportion of plant nutrients in mixed goods will rise to between 27 and 28 percent by 1975. The figure of

28 percent is used for some comparisons in this report. It should be mentioned, however, that the rate of increase in recent years has been such that an average concentration of 28 percent can be expected to be reached well before 1975.

The transportation advantages of higher concentrations spring from the fact that--with certain exceptions, such as sulfuric acid and phosphate rock--the same scale of rail and motor rates usually applies to all types of fertilizer and fertilizer materials, including superphosphate. Railroads and motor carriers publish fertilizer lists composed of more than 100 different commodities. The same rate applies to each of these freight items regardless of differences in value, proportion of plant nutrients, and other characteristics. The result is that the higher the concentration, the lower the transportation costs per ton of nutrients shipped.

The four rate curves in figure 8 portray the reduced rail transport costs per ton of plant nutrients made possible by increasing the concentration of fertilizers. The original rate basis for these comparisons is the maximum distance scale of fertilizer rates prescribed by the Interstate Commerce Commission for Southern Territory, increased to date. While actual point-to-point fertilizer rates may deviate to a small extent from this prescribed scale, it is the basis of the southern fertilizer rate structure and most actual rates are hinged directly upon it. Similar scales at nearly the same level generally apply in and between other rate territories. Figure 8 indicates, for example, that for a typical haul of 300 miles in Southern Territory the carload rates per ton of plant nutrients on concentrations of 18, 22, 28, and 45 percent are \$40.67, \$33.27, \$26.14, and \$16.27, respectively. Thus the rate per ton of $P_2O_5$ on 45 percent triple superphosphate is only 40 percent of that on 18 percent normal superphosphate.

The savings from shipping higher analysis fertilizers can create far-reaching economic benefits. The farmer frequently pays a lower delivered price for fertilizer per unit of plant nutrients. Less warehousing and storage space is required. Motor, water, and rail lines need to devote a smaller part of their scarce transportation equipment to hauling this heavy-moving commodity. To illustrate, the increase in plant-nutrient content of mixed fertilizers from 22.5 to 28 percent indicated as possible by 1975 represents a 24 percent increase in concentration. On this basis, transportation capacity to haul a 100 percent increase in consumption of plant nutrients would have to be increased only 61 percent in the next 25 years.

## EFFECTS ON PLANT LOCATION

It is certain that transportation costs will continue to form a substantial part of the final selling price of fertilizers. Consumption is widely distributed across the country, but in the case of phosphate rock--one of the principal raw materials--major deposits are located in only three areas, Tennessee, Florida, and four western States (Idaho, Montana, Utah, and Wyoming). Most of the reserves are in Florida and the western States and are distant from some of the major fertilizer-consuming areas. Utilization of these phosphates requires considerable transportation of either the raw material or the finished products. On the other hand, the desirability of minimizing transportation costs will undoubtedly mean that manufacturing centers will tend to be so located in relation to the raw materials sources and the market as to require the least possible tonnage movement. One transportation result of this tendency will be to place manufacturing plants nearer sources of raw materials as fertilizers become more highly concentrated.

## PRESENT AND FUTURE PLACE OF WATER TRANSPORT

Transportation costs, like others, are increasing substantially. Generally, transportation costs by land are increasing faster than those on waterways. This fact, coupled with rapid improvements in efficiency of water transportation achieved in recent years, should favor increased use of water transportation for fertilizer and fertilizer materials in the future. In total traffic, water transportation has grown relatively faster in recent years than the other transportation methods. Ton-miles of all traffic moved by the inland waterways in the past 20 years has increased 400 percent, compared with increases of 42 percent for rails and 380 percent for trucks.

Barge transportation of fertilizer in bulk form, instead of in bags or other containers, offers opportunities for substantial economies. This is particularly true of long, fairly direct barge shipments between ports or via rail-barge or truck-barge routes between inland points located relatively short distances from river transport. Figure 9 compares the rail mileage scale of maximum fertilizer rates in Southern Territory prescribed by the Interstate Commerce Commission with representative point-to-point published barge rates for like distances. Although the water route is usually longer than the rail route even for hauls between ports, in many instances the economy of waterway shipment is significant. There is already some barge movement of phosphate rock and phosphate fertilizer from Florida to Mississippi River points.

It is probable that distribution centers will develop at river ports where bulk fertilizer may be unloaded from barges and bagged

for subsequent overland distribution beyond. Or, to avoid the relatively high cost of bagging, barge-delivered bulk fertilizer may be loaded from barge or storage directly into spreader trucks or other vehicles which could carry the bulk material from such centers to farms for immediate application. This method of distribution would reduce the line-haul barge rate and eliminate not only cost of bagging but also the higher handling and storage costs usually incurred in the distribution of packaged freight.

## THE PROBLEM OF CONTAINERS

Solid fertilizer materials, such as potash salts and superphosphate, to be used as ingredients of mixed fertilizers are normally shipped in bulk. Anhydrous ammonia is transported under pressure in tanks. Nitrogen solutions are shipped in tanks, usually under slight pressure. Solid nitrogen materials, such as ammonium sulfate or sodium nitrate, are generally moved in bulk as materials or in bags when retailed as fertilizers. Ammonium nitrate, being a hygroscopic or moisture-absorbing material, is always packed in moisture-proof containers, usually multiwall paper bags with one or more plies of asphalted paper. Mixed fertilizers are normally sold in bags, although there is a growing tendency to transport fertilizers from retailer to farm in bulk form by ordinary or spreader truck.

Paper bags have replaced textile bags as fertilizer containers to an increasing extent in the last ten years or more, the principle reason being their lower cost. As they are amenable to rapid and semiautomatic filling, and can be closed with minimum trouble, paper bags are popular fertilizer containers.

Moisture-proof bags have played an important part in making possible the production and use of large tonnages of ammonium nitrate as fertilizer. In early practice during World War II asphalted burlap bags, closed by wire ties, were used for shipping ammonium nitrate. Later, multiwall moisture-proof paper bags, sewed instead of wired, were adopted. Present practice is generally to use either open-mouth or valve-closure bags with two asphalted plies for moisture-proofing.

In the event nitric acid is used in the treatment of rock phosphate to make fertilizers, the products will contain ammonium nitrate and will be somewhat bygroscopic. Such fertilizers will require packaging in moisture-proof bags similar to those used for ammonium nitrate.

No major difficulties or changes connected with fertilizer containers are foreseen. Improvements will be made in bags and in methods of filling and closing. An example of such improvements

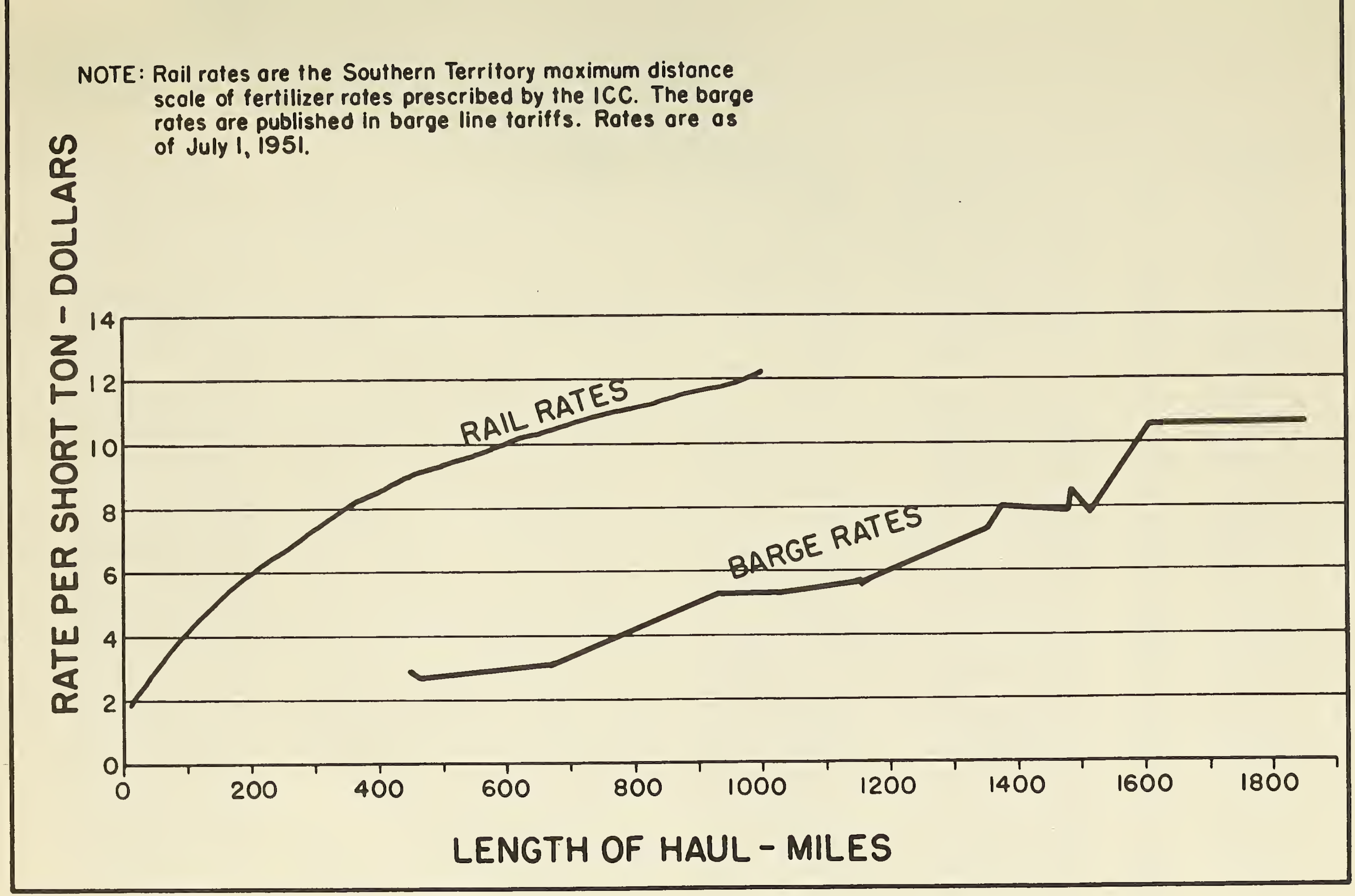


Figure 9. - Comparison of published barge rates with rail rate scale on fertilizers for various distances in the United States.

is the recent introduction of paper bags containing a ply of polyethylene-coated kraft as a moisture barrier in place of asphalted plies. Although presently more expensive than the asphalt-ply bag, this type of container promises to be extensively used.

## VIII. FACTORS THAT INFLUENCE THE GREATER USE OF FERTILIZERS

Many factors, foreseeable and unforeseen, can influence the use of fertilizer in the next twenty-five or more years. Discerning the nature of these influences is of practical interest in a look ahead, but no forecast of their measure is here attempted. In general, the major factors that influence the greater use of fertilizers may be listed for convenient reference in four categories: (1) public policy, (2) technological progress, (3) education, and (4) economic feasibility.

Public policy, as determined by democratic processes in this country, encourages the utilization of the human and physical resources of the Nation to meet the needs of a growing population, and it affords opportunity for expanding and rewarding the beneficial enterprise of its citizens. As regards the greater use of fertilizers, public policy favors the efficient utilization of our soil resources to contribute continually to the highest possible standard of living for the people of the United States.

As an example of the working of public policy in bringing about an increase in use of fertilizer, we may cite the materials furnished or payments made for fertilizer use in attaining conservation objectives. This has been particularly effective with respect to use of liming materials and superphosphates in connection with the growing of legumes and grasses. Such programs can bring about faster adoption of improved practices, including fertilizer use. Another example where public policy has contributed and can continue to contribute materially to influencing fertilizer use, is assistance to farmers in planning for the management and conservation of their lands. The attainment of sustained high-level production and the improvement of our soil resources, which is a major policy in the United States, will have a marked influence on the quantities of fertilizer and liming materials used.

Since the early days of the Nation, public policy has furthered the introduction, improvement, and distribution of plants to improve the quality of agricultural products and increase their abundance. Fertilizer research was, therefore, logically a subject of very early public interest in American agriculture. Under the influence of research the advance of the science of the production and use of fertilizers has accelerated, and research will doubtless continue to be the pioneering influence in this field.

The development of improved materials, both from the standpoint of plant-nutrient content and ease of handling, will have a marked effect on future use of fertilizers. Much progress has been made with respect to certain crops in determining the combinations of factors which give far greater results than when the practices are applied separately. Through adoption of the right kind of practices the effectiveness of fertilizer in increasing production is greatly multiplied. We appear to be on the threshold of outstanding progress in this field. With improved materials and their optimum application under proper conditions, fertilizer use will go forward to meet the demands for agricultural products.

Education, through the dissemination of knowledge and skills in the use of fertilizer and demonstration of its practical worth in farming, has also been supported by public policy. Educational activities on the part of government and industry—through various media, including radio, television, publications, meetings, tours, and demonstrations—will provide to the farmer the information necessary for securing efficient, increased use of fertilizer.

Finally, economic feasibility—the acid test for the introduction or continuation of specific farming practices—will largely determine the general acceptance and application of fertilizer recommendations in the future as in the past. In the economic factors also, public policy plays a part by encouraging demonstrations of soil-improving practices and by means of support prices when they are needed to encourage production of crops to meet national requirements. Gearing production to demand also stabilizes farm enterprises and thus encourages the most effective use of land and fertilizer. This in turn encourages greater commercial availability of fertilizers on the competitive basis of price, quality, and service.

But as we look ahead at the possible influence on fertilizer use of the factors of technological progress, education, and economic feasibility—all supported by public policy and dependent on integration with successful farming—it is evident that due consideration must also be given to the cumulative effect of all factors influencing crop production.

The cumulative value of getting the most from land, labor, capital, and marketing opportunity—through sound land-use and planned farm-management—are well recognized in application to the individual farm. Rapid progress has been made in recent years in experimentally testing the value of complementary and integrated farm enterprises and in demonstrating their practicality on hundreds of privately operated farms. This method of cooperating with farmers will undoubtedly continue to have an important influence on use of fertilizers.

The favorable influence of coordination of the research, educational, and economic factors under the guidance of public policy is becoming increasingly evident since the close of World War II. The progress made indicates much greater opportunities in the future. It seems probable that integration of these larger influences should become an indirect but powerful factor toward the greater use of fertilizer on farms through general programs such as the annual agricultural production guides, the full utilization of grasslands, soil testing, and the productive use and conservation of all agricultural lands, including woodlands.

Progress in these fields of endeavor inevitably results in the discovery of opportunities. Some of these opportunities may lie in the direction of better utilization of industrial and municipal wastes as fertilizer. Investigations of growth hormones and other factors affecting the capacity of the plant to utilize nutrients, as well as new techniques in plant breeding, offer interesting possibilities.

Fertilizer in new forms and formulas and the application of fertilizers in combination with other field operations, such as seeding, tillage, and the use of herbicides and irrigation water, indicate vistas of present research which may become more diverse and more extensive.

The progress of research and education prepares the way for further progress in farming. The continuing integrated use of research, education, and related services are factors influencing the use of fertilizer in the future. The economic feasibility of greater use of fertilizer is indicated by the increasing food and fiber requirements of a steadily growing population, accompanied by opportunity for expanding our capacity for agricultural production through further utilization and conservation of our total agricultural resources.

## IX. SUMMARY

Since the early days of the Nation, fertilizer has played an ever-increasing role in the production of the food and fiber required to feed and clothe our continually growing population. Because there is relatively little additional land to be brought into production, the expanding need for food and fiber must come mostly from improved cultural practices, including the greater and more wide-spread use of fertilizer.

The commercial fertilizer industry in the United States originated in Baltimore about 1850 and initially was based on wastes and byproducts, chiefly of organic origin. Today its

operations also include the fixation and transformation of atmospheric nitrogen, the mining and processing of phosphate rock and potash minerals and brines, and the manufacture of mixed fertilizers.

In 1900 nearly 90 percent of the commercial fertilizer nitrogen was derived from natural organic materials in comparison with less than 4 percent at present. Beginning with initial production in 1921, the proportion supplied by synthetic ammonia, and its products progressively increased to more than 65 percent of the total in 1950. Production of 1,565,569 tons of synthetic ammonia, more than double the output in 1946 and five times that in 1939, was achieved in 1950. Approximately 30 percent was used for nonagricultural purposes.

In 1950 the production of normal and triple superphosphate, which together supply about 90 percent of the $P_2O_5$ used annually as commercial fertilizer, totaled 1,993,515 tons of available $P_2O_5$ or 2-1/4 times that in 1940. With initial production of triple superphosphate in 1907, an output of 309,085 tons of available $P_2O_5$, or double the 1940 production, was also established in 1950.

Until World War I the potash requirements of American agriculture were met almost entirely by imports from Germany. Although production of potash from the natural brines of Searles Lake, California, began in 1916, initiation of production from deposits of soluble minerals in New Mexico in 1931 marked the beginning of developments which by 1941 had made the United States independent of foreign sources. Total production progressively increased to 1,286,762 short tons of $K_2O$ in 1950, or 3.4 times the output in 1940.

In 1950, the Nation used 19.8 million tons of fertilizer containing more than 4.4 million tons of nitrogen, $P_2O_5$, and $K_2O$. These quantities were respectively 1.9 and 2.1 times those used in 1942. and 7.2 and 11.2 times those used in 1900. Nevertheless the supply of plant nutrients generally has been insufficient to meet the demand since 1941.

Nearly 70 percent of commercial fertilizer is marketed in the form of mixtures. Such mixtures contain 50 to 60 percent of the N, about 70 percent of the $P_2O_5$, and more than 90 percent of the $K_2O$ used as fertilizer.

Although the average concentration of primary plant nutrients in mixed fertilizers increased 27 percent from 18.3 percent in 1933-34 to 23.2 percent in 1949-50, the increase in concentration did not keep pace with that of the fertilizer materials used therein. In consequence the average plant-nutrient content can be raised considerably with much economy to the farmer.

For many years the South Atlantic and South Central States have led in the consumption of fertilizer. These states retained leadership in N use in 1949-50 by a wide margin but the North Central States attained first rank in use of available $P_2O_5$ and also of $K_2O$, and were second only to the South Atlantic States in the use of total primary nutrients.

Changes in the pattern of fertilizer consumption by crops have resulted in recent years from land-use and conservation programs. During the period 1929 to 1950 the trend in the proportionate use of all fertilizer was upward for corn, small grains, hay, pasture and vegetables. The reverse was true for such cash crops as cotton, tobacco, and potatoes, although in each case except cotton the tonnage of fertilizer used on these crops increased.

The total consumption of liming materials in 1950 was 26.5 million tons, or 8 times that in 1935. Of the total quantity in 1950, 70 percent was used in the North Central and 11 percent in the South Atlantic States. Use on pasture accounted for 16 percent of the total in 1947.

Formerly, commercial fertilizer materials were used entirely in the form of solids. Today, however, large quantities of ammonia, phosphoric acid, and mixed fertilizers are applied to the soil in liquid form. In addition, more than 300,000 tons of nitrogen in liquid form are now used annually in the domestic manufacture of mixed fertilizers. Spraying of apple trees with urea solutions is an important example of recent developments in the foliage application of plant nutrients.

In 1911 to 1949 the national annual expenditure for farm fertilizer has averaged 5 percent of the farmers' cash income in the previous year from crops and Government payments, exclusive of the livestock industry. An upward trend can be expected in the future because of rapidly growing realization of the importance of fertilizers in crop production and in the maintenance and improvement of soil fertility, particularly in the newer areas of use.

Fertilizer placement with respect to seed and plant is a very important factor in crop stands and yields and in fertilizer efficiency. Machines of various types and sizes are now on the market for applying and placing fertilizers in accordance with approved practices.

Bulk distribution of anhydrous ammonia, ground phosphate rock, superphosphate, and mixed fertilizers from the plant, storage depot, or freight car directly to the soil, on a custom basis, has recently come into considerable practice in some parts of the country. Since the cost of fertilizer distributed in this way is reported to be less than by the customary procedures, the practice can be expected to increase.

Soil and climatic factors, the balance between feed-crop and cash-crop production, and the relative importance of livestock in the farming system, all influence the quantity and kind of fertilizer used. Improved conservation and land-management practices create conditions whereby the point of marginal returns from fertilizer is extended, and are accompanied by large increases in the use of all plant nutrients.

The opportunity for increasing yields of corn, small grains, other field crops, and hay and pasture is very great since current rates of nutrient use on these crops are far short of what would be most profitable even at current levels of other practices.

If farmers improved other practices on the corn crop, about 50 percent over current levels, and applied about half as much fertilizer as would be most profitable, the increase in yield would be somewhat above 20 percent.

Use of approximately 35 percent more plant nutrients in conjunction with a 50 percent improvement in other practices might result in an increase of about 70 percent in the yield of seed cotton. The yield probably could be doubled at the most profitable rate of fertilizer use.

Using considerably more nitrogen but less phosphate and potash in the fertilizer combination and improving other practices by 50 percent would probably increase the yield of vegetable crops by more than 25 percent and would be more profitable.

Curves of response to N, to $P_2O_5$, and to $K_2O$, together with current price relations for these nutrients, indicate that the current average yield on hay and pasture is little more than one-third the yield that could be obtained by going half way toward the most profitable rates of application and making a 50 percent improvement in other practices. At the most profitable rates, the optimum $N$-$P_2O_5$-$K_2O$ ratio would be approximately 1-2.3-2.5 in comparison to the current ratio of 1-14.5-2.5.

At something approaching a half-way mark, both with respect to rates of plant-nutrient application and to levels of other practices, four to five times the current use of plant nutrients on corn, cotton, vegetables, hay, and pasture crops, probably would result in approximately double the production now attained.

Estimated agricultural production needs by 1975 are approximately 40 percent above current production levels.

Depending upon developments in farming practices and estimated output 40 percent higher than current levels, consumption of plant nutrients in the United States could range anywhere between about 10 and 14 million tons.

Although 25 to 30 million tons of liming materials currently are used, an annual application of nearly 80 million tons would be beneficial. Probably less than half the needed increase will be achieved by 1975.

Total annual applications of trace-element materials now approach 150,000 tons and a three- or fourfold increase may be expected during the next two or three decades.

Applications of sulfur-carrying materials may be required in some areas to offset the increased use of sulfur-free phosphate fertilizers.

The United States has no commercial deposits of natural nitrates. Domestic sources of nitrogen for fertilizer use comprise natural organic materials, byproducts of industrial operations such as the coking of coal, and products of the synthetic ammonia industry. The prospective lignite and oil shale industries are potential sources of byproduct nitrogen. The synthetic ammonia industry currently is the principal source and may be expanded to meet any future demands.

The United States not only is virtually independent of foreign sources of phosphate rock but supplies large quantities of this material to the world markets. Of the total world reserve of more than 46 billion long tons of phosphate rock, French North Africa (Algeria, Morocco, and Tunisia) has 51 percent, the United States 29 percent, and the Soviet Union 16 percent.

The present minable or economic reserve of phosphate rock in the United States totals about 4 billion long tons, of which approximately 1.5 billion are in the Western States, 0.1 billion in Tennessee, and most of the remainder in Florida. Improvements and developments in the methods and techniques of the mining, beneficiation, and processing of mineral phosphates will bring additional large quantities of these materials into the economic reserves.

The Nation's proved gross reserve of potash economically minable under present conditions amounts to approximately 250 million short tons of $K_2O$ located in the New Mexico deposits of highly soluble minerals and in the brines of Searles Lake, Calif., and Salduro Marsh, Utah. This figure represents the total potash in such deposits and brines. It makes no allowance for the nonrecoverable potash therein, which varies among the deposits and with different mining and refining practices. The country has huge resources of potash in other minerals and rocks, such as polyhalite in Texas and New Mexico, greensands of the eastern seaboard, Georgia shales, Wyoming leucite, Utah alunite, potash feldspars, and porphyry copper mine tailings that, in general, are not amenable to economical mining

or processing under present conditions. Consideration should continue to be given to methods for economic utilization of presently marginal and submarginal materials, particularly for production of sulfate salts.

Calcium and magnesium in inexpensive carbonate forms suitable for agricultural use occur in almost unlimited quantities in practically every state in the Union and present no problem of overall supply.

At current rates of use known reserves of native sulfur will be exhausted in the United States and possibly in the free world by 1975. The plant-nutrient requirements for sulfur, which are now supplied largely by normal superphosphate and ammonium sulfate, could be furnished by mineral calcium sulfates in many parts of the country. However, as justified by need and prices, almost unlimited supplies of sulfur may be obtained from pyrites, calcium and other sulfates, and other sources.

Reserves of boron in the United States are such that adequate supplies will present no problem in the forseeable future.

The United States will need to supplement its domestic production of copper, manganese, and zinc by imports from the more abundant foreign sources.

With a few exceptions the capacity for producing N, $P_2O_5$, and $K_2O$ has not kept pace fully with the demand for such nutrients in recent years. Of the commercial fertilizer nitrogen consumed in the United States in 1950, natural organics supplied 5, natural Chilean nitrates 10, coal 20, and atmospheric nitrogen 65 percent. Even greater dependence necessarily will be placed on atmospheric nitrogen in the future.

From its beginning in the United States in 1921, the synthetic ammonia industry has expanded, very rapidly since 1940, to the point where the facilities in 1951 comprised 21 plants with an estimated total capacity of 1,616,000 short tons of nitrogen annually. Additional capacity totaling more than 600,000 tons of nitrogen annually, was recommended or under consideration during the first 7 months of 1951. Of our capacity in 1951, 4 percent was based on byproduct electrolytic hydrogen, 44 percent on hydrogen produced with coke, and 52 percent on hydrogen from natural gas. As natural gas becomes increasingly more expensive, it is expected that the synthetic ammonia industry ultimately will be dependent primarily on coal for hydrogen production.

Anhydrous ammonia is the cheapest and most concentrated nitrogen fertilizer material, and its use should be encouraged and expanded within the limits imposed by economic considerations and by local soil conditions and farming practices. Of the solid

nitrogen materials, urea and ammonium nitrate are the most concentrated. Effort should be directed especially toward production of urea since it is the more concentrated, has important industrial and technical uses, and also is valuable as a nitrogen supplement in feeds for ruminants.

Total capacity for production of phosphate fertilizers amounted to nearly 3,100,000 short tons of available $P_2O_5$ per year on June 1, 1951. Of this capacity, which is contained in more than 235 plants, 84 percent is for production of normal superphosphate and 10 percent for triple superphosphate. Additional capacity totaling more than 200,000 tons of $P_2O_5$, all in the form of triple superphosphate and other concentrated products, was recommended or under consideration during the first 7 months of 1951. In 1950, seven plants produced triple superphosphate with wet-process phosphoric acid, and two plants used virgin and spent electric-furnace acid, respectively.

Of eight plants manufacturing wet-process acid at least two market some liquid phosphoric acid for direct application, chiefly for addition to irrigation water. The choice between wet and furnace processes for phosphoric acid production depends primarily on the unit cost at which the available $P_2O_5$ in the final products can be placed in the soil. Tho outlook appears to be more promising for eventual economic application of furnace processes to the western phosphates than to those of Florida and Tennessee.

Widespread marketing of fertilizer-grade liquid phosphoric acid would permit manufacture of superphosphate containing 30 percent or more $P_2O_5$ with mixtures of phosphoric and sulfuric acids with little or no change in present facilities and equipment. The products obtained would be suitable for use in the preparation of high-analysis mixed fertilizers with resultant savings to the farmer in the cost of plant nutrients because of lower unit costs for handling, packaging, and transporting.

The economic status of several furnace processes for the manufacture of fertilizers directly from phosphate rock is as yet rather poorly defined. Such processes yield products in which the $P_2O_5$ is insoluble in water but is well utilized by many crops on nonalkaline soils.

Nitric acid is as effective as sulfuric acid in decomposing phosphate rock although special treatment is required to obtain fertilizer products having satisfactory physical condition. Since nitric acid processes offer a major opportunity for conservation of sulfuric acid in the manufacture of fertilizers, their adoption in the United States should be encouraged to the fullest possible extent.

Supplies of acids—whether sulfuric, nitric, or other acids—must be made available to meet the requirements of processes

involving treatment of phosphate rock for recovery of uranium as a coproduct in the manufacture of high-analysis fertilizers and other phosphate products.

Over 95 percent of the potash produced in the United States comes from brines and deposits of highly soluble minerals. As of March 1951, the estimated total capacity for production of potash in the United States amounted to 1,350,000 tons of $K_2O$, mostly in the form of potassium chloride. Two new plants with a total initial capacity of about 370,000 tons of $K_2O$ per year are under construction in New Mexico and are expected to be in operation by 1953. Additional new operations and expansions of existing facilities are under consideration.

The sulfur problem in fertilizers is primarily one of obtaining the sulfuric acid for processing phosphate rock and manufacturing ammonium sulfate, rather than of securing adequate sources of nutrient sulfur.

The problem of adequate supplies of calcium and magnesium, except magnesium in water-soluble form, will continue to be met by relatively simple and economically located processing facilities.

Facilities for producing the plant-nutrient forms of boron, copper, manganese, and zinc are adequate for the present demand, but imports of the latter three elements may be anticipated.

About 950 different grades of mixed fertilizers are manufactured by more than 800 companies and individuals in approximately 1,200 plants having an estimated annual capacity of about 21.5 million short tons in comparison with the 12,309,000 tons consumed in the United States and Territories in the year ended June 30, 1950.

Production of granular mixtures has received much attention in recent years and is gathering momentum. Current and future expansions in the production of concentrated phosphate materials can be expected to further the manufacture of granular high-analysis mixtures.

Although industrial and municipal wastes at best can be expected to supply only a small portion of the Nation's plant-nutrient requirements, their utilization is important as a conservation measure and especially to reduce stream and atmospheric pollution and other health hazards.

The total reproduction cost of all of the Nation's facilities for fertilizer production would likely be well over a billion dollars. Reproduction costs of fertilizer-manufacturing plants, exclusive of facilities for mining and concentrating phosphate rock, producing sulfuric acid, quarrying and processing limestone,

and recovering wastes approaches 809 million dollars, while the actual value—allowing for depreciation because of age, usage, and obsolescence—is nearly 617 million dollars.

In addition to the plants in operation in July 1951, new facilities having a total estimated value of 146 million dollars were either under construction or recommended for construction.

Except during emergencies, the United States has imposed no restrictions on the import or export of fertilizers and fertilizer materials.

The United States is relatively self-sufficient in fertilizer nitrogen although imports usually exceed exports. If the current price differential between natural Chilean sodium nitrate and the domestic synthetic product continues, it is probable that smaller quantities of nitrogen will be imported from Chile in the future. Nitrogen exports may be expected to decrease with completion of rehabilitation and assistance programs in foreign countries.

For many years the United States has exported large quantities of phosphate rock and at the same time has imported small amounts. In 1950 the exports totaled 1,832,000 long tons and imports only 87,000 tons. Aside from phosphate rock, the United States imported 42,000 short tons of $P_2O_5$ in fertilizers in the year ended June 30, 1951, and exported 83,000 tons. It appears that the developing demand for phosphate fertilizers in the free world may favor expansion of the export trade in both processed and unprocessed phosphates.

In the year ended June 30, 1951 the United States imported fertilizers containing 203,000 short tons $K_2O$ and exported 67,000 tons. Although imports probably will continue to be substantial, the fast developing United States industry is expected to be able to meet the growing domestic requirements for potash and to provide for some exports.

Transportation problems are of major concern in the manufacture and use of fertilizer. In 1949 the railroads transported 15,562,928 short tons of fertilizer and fertilizer materials and 17,685,149 tons of phosphate rock, or a total of 33,248,077 tons of fertilizer and phosphate rock. Inland and coastal waterways moved 5,135,031 tons, of which about 2,950,000 tons were phosphate rock. Statistics of truck movements are not available.

During the period 1939 to 1950, transportation costs on the final products accounted for 10 to 14 percent of the value of the fertilizer at its destination. Since transportation rates are based on gross weight, shipping costs are lower per nutrient unit

the higher the nutrient content. As the fertilizers marketed become more highly concentrated in relation to the raw materials, manufacturing plants will tend to be placed nearer the sources of raw materials.

No major difficulties or changes connected with fertilizer containers are foreseen.

In general, the major factors that influence the greater use of fertilizers are: (1) public policy encouraging the efficient utilization of soil resources to attain the highest possible standard of living for the people of the United States, (2) technological progress in the development of improved materials and knowledge of their optimum rates of application as affected by other cultural practices, (3) educational activities of all types providing the farmer with the information necessary for securing efficient use of fertilizer, and (4) economic feasibility—the acid test for the introduction, continuation, or expansion of specific farming practices.

It seems probable that integration of all these influences will become an indirect but powerful factor toward the greater use of fertilizer on farms through general programs such as the annual agricultural production guides, the full utilization of grasslands, soil testing, and the productive use and conservation of all agricultural lands, including woodlands.